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SOLAR RADIATION IN SAUDI ARABIA

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Original solar irradiance data were obtained from the U.S. Air Force Environmental Technical Applications Center. These data were based on a model which used standard meteorological data and an albedo supplied by us. A procedure was developed to interpolate missing solar irradiances, and serially complete sets of hourly total solar irradiances were established for the three Saudi Arabian stations Riyadh, Dhahran, and Quasumah for the period January 1981 through July 1990. Tables of maximum, minimum, and mean daily totals, mean hourly values, and frequency distributions for noon are included. Comparison of monthly means and extremes with published data did not produce conclusive results. Considerable disagreement exists among published amounts of solar radiation reaching the surface in this region. The solar irradiance estimates in this report agree with the highest published values and should be considered upper limits.

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I. INTRODUCTION

This publication is a companion to the report (Dudel et al., 1992) about temperatures in Saudi Arabia during the decade 1981-1990. Input files for both studies of hourly variations at Riyadh, Qaisumah, and Dhahran were provided by the U.S. Air Force Environmental Technical Applications Center (ETAC) which functions as part of the Air Weather Service (AWS). Since actual observations of hourly solar irradiance were not available to ETAC, the data which we received were based on an ETAC in-house model that estimates global solar irradiance from astronomical information and from cloud data found in standard meteorological reports.

Section II of this report contains background information. First, some of the numerous sets of units and related terminology are considered. Some general background on atmospheric turbidity is also discussed. This includes reference to urban effects, climatic trends, and differences between desert areas and typical higher-latitude climates.

Serially-completed files for the period January 1981 through July 1990 were established by interpolating for missing data in the original ETAC files. Data points for three-hourly data were seldom missing, in the original files, but those for in-between hours were scarce. Section III discusses the original data in more detail and explains the interpolation procedure. That section also contains 17 tables which summarize the results of the data analysis. Section IV discusses the comparison of our results with published data throughout the area. Finally, Section V contains a summary and conclusions.

II. BACKGROUND INFORMATION

A. Units and Terminology

Many different systems of units are used in energy studies, and sometimes the terminology varies. The term radiation is often used as a synonym for radiant energy, but the preferred definition considers radiation to be the process by which electromagnetic energy is propagated. Meteorologists have traditionally used the calorie as the unit of energy. One calorie equals 4.19 joules, $4.19(10^7)$ ergs, or 0.00397 British thermal units. The rate of flow of radiant energy per unit time is called radiant flux or power. A common unit of radiant flux is the watt which equals one joule per second. A total energy of 1 Wh (or 3600 J) is received on a surface in one hour if the radiant flux is 1 W for 1 hour. Radiant flux incident upon a unit surface is called radiant flux density or irradiance. An irradiance of $1\ W\ m^{-2}$ is equal to $0.00143\ cal\ cm^{-2}\ min^{-1}$. Occasionally meteorologists use intensity as a synonym for radiant flux density even though this is inconsistent with radiometric usage.

The rate at which energy from the sun is received outside the atmosphere at the mean earth-sun distance on a unit area perpendicular to the incident solar rays is called the solar constant. Determinations of the solar constant generally produce radiant flux densities within the range 1.9-2.0 cal cm^{-2} min^{-1}. Comparisons of measuring techniques and standards account for many of the differences among investigators. Real variations in solar output are apparently only a few tenths of one percent after possible errors of measurement have been corrected. Numerous references to the literature on the solar constant may be found in Mecherikunnel et al. (1988) and Kessler (1985). ASHRAE (1989) states that the currently accepted solar constant is 1370 W m^{-2}. This is equal to 1.96 cal cm^{-2} min^{-1}.

The solar irradiance at the top of the atmosphere follows an annual cycle because the orbit of the earth around the sun is not a circle. These values are given in the *ASHRAE Handbook, Fundamentals* (ASHRAE, 1989).

Approximately half of the solar energy is within the visible limits 0.4-0.7 μm, and 99.9 percent is within the range 0.15-4.0 μm (Huschke, 1959). Solar radiation is often called short wave radiation to distinguish it from atmospheric radiation which lies almost entirely within the wavelength interval 3-80 μm. Instruments for measuring solar irradiance at the surface are usually sensitive in the wavelength interval 0.28-2.8 μm. Virtually all solar energy at shorter and longer wavelengths is absorbed by the atmosphere before it can reach the surface of the earth.

The total solar irradiance on a horizontal surface is called global irradiance. One component of the global irradiance has followed a direct path to the surface. The other component is diffuse and consists of energy which has been scattered by the atmosphere.

The diffuse fraction of solar irradiance varies according to meteorological conditions. El-Salam and Sayigh (1977) found an average of 0.175 for the fraction of diffuse radiation at some Saudi Arabian stations in the absence of clouds. They found that clouds could cause the diffuse fraction to be up to 0.6 depending upon the amount of cloud cover. Alnaser (1989) computed monthly mean diffuse and global radiations for Bahrain. The lowest monthly mean ratio of these two quantities was 0.217 in October, and the highest was 0.346 in December. At six stations in Yemen, Khogali et al. (1983) found that measurements of the diffuse fraction of solar radiation varied from 0.127 to 0.446. At Baghdad, the average monthly diffuse fraction of global radiation ranges between 0.364 in November and 0.256 in September (Al-Riahi et al., 1990). Elhadidy and Abdel-Nabi (1991) found that at Dhahran the diffuse fraction was 0.11 on a typical clear day in March and 0.91 on a very dusty day in the same month.

B. Atmospheric Turbidity

Turbidity in meteorology is any condition which reduces atmospheric transparency to radiation, especially to visible radiation (Huschke, 1959). It is usually applied to a cloud-free portion of the atmosphere where transmittance is reduced by air molecules and by particles such as smoke, dust, and haze. Thus, one would expect turbidity in desert climates to vary by season. Al-Jamal et al.

(1987) found that atmospheric turbidity in Kuwait is higher in warmer months and is particularly large in June and July. During much of the year in Kuwait, aerosol attenuation is as large as or larger than the sum of the attenuation by ozone, water vapor, and molecular absorption by other gases.

Turbidity is typically expressed according to the Angström turbidity coefficient or the Linke turbidity factor. The procedures for calculating these two parameters will not be discussed here. Abdelrahman et al. (1988) found that the two parameters are approximately linearly related to each other.

Evidence indicates that atmospheric turbidity is greater in desert climates than in temperate climates. Abdelrahman and Nimmo (1984) examined the Ångström turbidity coefficient for July 1980 through June 1981 for Dhahran. July had the highest turbidity. Abdelrahman and Nimmo compared this with the scientific literature on the month with the highest turbidity at several other locations. The Ångström turbidity coefficient for Dhahran was approximately ten times that for Davos, Switzerland, and twice that for Los Angeles. Abdelrahman et al. (1988) compared the Linke turbidity factors for Dhahran and Avignon, France. They found that the ratio of the Linke factor at Dhahran to that at Avignon averaged 1.6 during the warmer months and 1.8 for October through March.

Cess and Vulis (1989) and Cess et al. (1991) examined satellite measurements to compare surface flux of solar energy with flux at the top of the atmosphere over oceans, vegetated surfaces, and deserts. For a given flux at the top of the atmosphere in the absence of clouds, the associated flux at the surface of a desert is approximately 83 percent or less of the flux at the surface of an ocean. The magnitude of the flux at a vegetated surface is intermediate between these but is closer to the flux at the surface of an ocean.

Ackerman and Cox (1982) found large day-to-day variability of dust over the desert area of the Arabian Peninsula during spring and summer of 1979. Clear-sky absorption of shortwave energy in a dust-laden atmosphere was approximately twice the absorption in the absence of dust, but longwave radiative fluxes were not significantly affected. Research aircraft measured dust concentrations as high as 3000 $\mu g\ m^{-3}$ on several flights.

El-Shobokshy et al. (1990) also found considerable variability when they examined inhalable particles 25 m above ground at a site approximately 15 km northwest of the center of Riyadh from 1 March to 31 May 1988. Concentrations of inhalable particles in 92 samples taken during dry weather ranged from 0.14 to 5080 $\mu g\ m^{-3}$, with a mean of 639 $\mu g\ m^{-3}$. El-Shobokshy et al. mention another study at a different site in Riyadh during the early summer when several measurements exceeded 1000 $\mu g\ m^{-3}$. High particle concentrations at Riyadh are not surprising because it is a rapidly growing city with more than one million people. Industries are located 15 to 20 km southeast of the center of the city.

Urbanization and industrialization can cause localized increases in atmospheric turbidity within a climatic zone. Urbanization increases turbidity by a factor of two and industrialization increases turbidity by a factor of four according to Dogniaux (1976).

Increases in atmospheric turbidity began to be apparent some time ago. As an example from the Middle East, Joseph and Manes (1971) examined two sizable pyrheliometric data sets for the years 1930-34 and 1961-68 at Jerusalem. The Ångström turbidity factor increased by 10 percent per decade during this period of time. The number of motor vehicles registered in Jerusalem was 15000 in 1968, an increase from an estimated 1000 in 1932. Population increased only slightly during the period. Joseph and Manes concluded that local pollution did not explain such a large change of turbidity and that non-local influences must be important.

More recently, global radiation measurements from thermoelectric pyranometers at stations with very small changes in station coordinates from 1958 to 1985 were examined by Stanhill and Moreshet (1992a). They found a 5.3 percent reduction of annual mean insolation for land surfaces if observations were weighted according to the amount of land each represented. Of the 46 stations with little or no site movement, Bet Dagan in Israel was the closest to Saudi Arabia and was also the station with the largest change of annual insolation from 1958 to 1985. Annual mean insolation at Bet Dagan decreased 22.1 percent from 1958 to 1985.

Stanhill and Moreshet attributed most of the large negative trend of insolation at Bet Dagan to increased local pollution. Motor vehicle traffic on two nearby roads has increased from an estimated 1000 per day in 1958 to 90000 per day in 1985. The Tel Aviv metropolitan area is upwind from the pyranometer site, and the center of the city is only about 8.5 km from the current pyranometer site. A major electricity-generating power plant began operation approximately 12 km upwind from Bet Dagan during the period, and it burns 0.5 million tons of fuel per year.

Stanhill and Moreshet (1992b) examined data for Bet Dagan in more detail in a subsequent article. The observation period was 1956-1987. The site moved 8.5 km west during 1962 and changed elevation from 40 m to 30 m. Between 1956 and 1987 the annual average reduction was 0.63 percent per year. The amount of cloud cover did not show a trend during this period.

Evidence that anthropogenic sources, especially automobile traffic, strongly influence insolation at Bet Dagan comes from measurements on the Day of Atonement and on seven preceding and seven subsequent days. The average for the Day of Atonement for the years 1963-1972 and 1974-1983 had 10 percent greater global irradiance than the seven preceding and seven subsequent days. Insolation on the Day of Atonement when there was massive traffic associated with mobilization for war in 1973 was 16.430 MJ m^{-2}, much less than the mean of 20.074 MJ m^{-2} for the Days of Atonement during the ten preceding and ten following years.

III. ETAC DATA

A. Original Data

The global solar irradiance data from ETAC were produced by a model which used astronomical data, surface albedo, and reported low, middle, and high clouds to calculate the expected solar irradiance. ETAC did not make details of the model algorithms available to the authors. Comparison of time series of model output values with the separately available synoptic weather reports did not generally indicate that meteorological visibility or data on dust storms influence ETAC model output. Nevertheless, it was decided to use ETAC data to be consistent with our previous study of temperatures (Dudel et al., 1992) which depended upon data from ETAC for the same locations. In the next section, results of analysis of ETAC data are compared with summary information in the literature.

The surface albedo required by ETAC was assumed to be 0.35, an average based on desert locations in the literature. At one desert site in Saudi Arabia, Smith (1986a) found a total albedo of a little less than 0.36 at noon and slightly more than 0.40 near sunrise and sunset. Smith found that visible albedos were lower and infrared albedos were higher. On a map published by Ramanathan (1987), albedos varied from 0.25 at the southern border of the Arabian Peninsula to nearly 0.35 in the northeast. Staylor and Suttles (1986) studied models for surface albedos in deserts. Measured values for the Saudi Arabian desert on one of the graphs vary from 0.30 to 0.39. Arino et al. (1991) derived surface albedos for different types of surfaces. An albedo of 0.35 for a desert surface is consistent with their data which are based mainly on Africa, but one of their very small figures includes Saudi Arabia.

Table 1 contains the percent of missing data from ETAC for Riyadh, Qaisumah, and Dhahran. Time is coordinated universal time (UT or UTC), which is three hours earlier than local time in Saudi Arabia. Therefore noon local standard time is 0900 UT.

The record for June is particularly good, especially at Dhahran where the percent missing for June is 0.7 at 0600 UT and 1.0 at 0900 UT. Actually, the record for Dhahran is good throughout the months January through July. During this period the highest percent missing for Dhahran is the 4.2 percent for 0900 for March.

ETAC obtained required cloud information from DATSAV files of hourly meteorological observations. DATSAV files contain information merged from two separate teletype transmissions: hourly aviation weather reports in the METAR code and three-hourly synoptic weather reports coded in World Meteorological Organization (WMO) SYNOP code for the synoptic hours 00 UT, 03 UT, 06 UT, etc.

When it was noted that much larger percentages were missing during August through November, the data points were examined in more detail. Tables 2 through 5 show the number of data points which were not marked as missing for March, June, September and December, respectively. Three-hourly data are present in a large majority of cases at all three stations for March and June, and thus it appears that the SYNOP reports were regularly received. Receipt of METAR reports is apparently less reliable because intermediate hours have considerable numbers of data missing except at times when sunshine is astronomically impossible. Riyadh and Dhahran have better data at intermediate hours than has Qaisumah.

Missing values are not randomly distributed by year in September. Most data are missing during daylight hours in September 1990. Most of the missing data points are also in 1990 in December, but more than half of the values are present at 0900 UT. A more careful check of the data showed that from the middle of August through most of November 1990 global irradiances in ETAC data were sporadic, and December 1990 had poor data. More detailed examination showed that the onset of the data loss was in August 1990 when the Desert Shield activity began. The period January 1981 through July 1990 is used for analysis in subsequent sections of this report.

B. Interpolation Procedure

All available ETAC values were accepted as correct, and interpolation was used for missing values. Missing three-hourly values were extrapolated using persistence from the previous day, and other values during the day were interpolated or extrapolated to obtain a missing value S_2 according to the formula

$$(S_2 - S_1)/(S_3 - S_1) = (G_2 - G_1)/(G_3 - G_1) \tag{1}$$

where G is the clear-air global irradiance from the simple ASHRAE model (ASHRAE, 1989). G_i can be computed for all i, and Equation (1) assumes that S_2 is the only unknown S_i. In the following discussion, some of the symbols are not the same as the ones used by ASHRAE. The global irradiance G can be expressed as the sum of contributions from diffuse and direct irradiances as follows:

$$G = (C + \cos z)I_{DN} \tag{2}$$

where C is the diffuse radiation factor, z is the zenith angle, and I_{DN} is the direct solar irradiance on a surface normal to the incoming solar rays. The solar zenith angle is the complement of the solar elevation angle or solar altitude and it follows that

$$\cos z = \sin E \tag{3}$$

where E is the solar altitude.

The direct normal solar irradiance at the surface on a clear day depends upon the optical air mass, extinction coefficient, and energy at the top of the atmosphere. The optical air mass is unity for the vertical atmospheric path traversed by solar rays when the zenith angle is zero. For zenith angles less than 80°, a good approximation to the air mass is sec z. This approximation was replaced by the Bemporad value (List, 1971) for large solar zenith angles in the present study. The equation for the direct normal solar irradiance when the optical air mass equals sec z is

$$I_{DN} = A \exp(-B/\cos z) \tag{4}$$

where A is the apparent solar irradiance at zero air mass and B is the extinction coefficient. The actual solar irradiance at the top of the atmosphere is always greater than A because solar energy with the shortest and longest wavelengths is entirely absorbed by one air mass and never makes a contribution to solar energy at the surface. Equation (4) does not apply when the sun is below the horizon. For interpolation, the A, B, and C values derived for each day for Dhahran by Kruss et al. (1989) were used. These are $A = 1.0880 - 2.07549(10^{-3})J + 1.49005(10^{-5})J^2 - 1.40264(10^{-7})J^3 + 6.13476(10^{-10})J^4 - 8.15963(10^{-13})J^5$; $B = 1.68185(10^{-1}) - 1.97679(10^{-6})J - 3.67366(10^{-6})J^2 + 1.06608(10^{-7})J^3 - 5.07017(10^{-10})J^4 - 1.08026(10^{-13})J^5 + 4.34192(10^{-15})J^6 - 6.09205(10^{-18})J^7$; $C = 1.1155(10^{-1}) + 6.00929(10^{-5})J + 2.49623(10^{-5})J^2 - 1.41811(10^{-7})J^3 + 1.99555(10^{-10})J^4$, where J is the Julian date.

When equations (2), (3), and (4) are combined, the global irradiance can be written as

$$G = (C + \sin E)\, A \exp(-B/\sin E). \tag{5}$$

The solar elevation angle can be determined from

$$\sin E = \cos L \cos \delta \cos H + \sin L \sin \delta \tag{6}$$

where L is the latitude, δ is the solar declination, and H is the hour angle. The declination is -23.45° at the solstice in December and +23.45° at the solstice in June. The solar declination is zero at the vernal and autumnal equinoxes. Intermediate values can be found in astronomical tables.

C. Analysis

After interpolation for all missing values was completed for January 1981-July 1990, the new serially complete set of data was examined more thoroughly. Tables 6, 7, and 8 give the maximum, mean, and minimum daily solar energy for each month of each year at the three stations. Year-to-year variation for a given month is much larger for minimum daily solar energy than it is for maximum daily solar energy reaching the earth. This is true in both warmer and cooler parts of the year. An example is June at Dhahran where the maximum daily solar energy ranged from 8911 Wh m^{-2} in June 1986 to 8941 Wh m^{-2} in June 1982 while the minima ranged from 6266 Wh m^{-2} in June 1986 to 8791 Wh m^{-2} in June 1981. In December at Dhahran the maximum daily solar energy ranged from 4590 Wh m^{-2} in December 1983 to 4705 Wh m^{-2} in December 1985 while minima ranged from 1704 Wh m^{-2} in December 1984 to 3202 Wh m^{-2} in December 1981.

Tables 9, 10, and 11 give the maximum, mean, and minimum solar irradiances as a function of month and hour from the serially completed sets of data for Riyadh, Qaisumah, and Dhahran, respectively. Means are much closer to maxima than to minima throughout the day during the entire year at all three stations. In warmer months during the middle of the day, means are within a few percent of the maxima but are larger than minima by 50 percent or more. An example occurs at Riyadh at local noon (0900 UT) in June when the maximum irradiance is 1056 W m^{-2}, the mean is 1048 W m^{-2}, and the minimum is 692 W m^{-2}.

Figure 1 shows the diurnal variation of the maximum, minimum, and mean global solar irradiance for Qaisumah during June and December. Because Qaisumah at 46°07'E is not too far from the center of the time zone, most of the curves show considerable symmetry about noon local standard time (0900 UT). Minimum irradiances for June are markedly asymmetrical. This may be the result of cloudy conditions on one or a very few afternoons. Whatever the causes, they did not exist with sufficient frequency to cause the mean to deviate strongly from symmetry.

Tables 12, 13, and 14 show the frequencies of the irradiances at noon local Saudi Arabian time. The total number of data points is 310 for January, March, May, and July, 300 for April and June, 282 for February, 279 for August, October, and December, and 270 for September and November. Frequencies are listed in intervals of 10 W m^{-2}. In June, the interval 1050-1059 W m^{-2} contains 283 irradiances at Riyadh, 254 at Qaisumah, and 276 at Dhahran. The tendency for the preponderance of values to be in a limited range is stronger near the summer solstice than near the winter solstice. It is possible that measured irradiances would show a larger dispersion than these model outputs. However, conditions in the warmer part of the year can remain essentially the same for much longer periods in northern parts of Saudi Arabia than in middle latitudes.

Evidence of small variation in weather in June is found in measured maximum temperatures for Riyadh (Dudel et al., 1992). The absolute maximum temperature at Riyadh in June during 1981-1990 was 46.2 °C, and the average daily maximum was 41.9 °C. The lowest maximum temperature at Riyadh on any day in June during the entire ten-year period was 38.0 °C.

Figures 2 through 4 illustrate the data for December, March, June, and September expressed as cumulative frequency distributions. The ordinate is percent and the abscissa is irradiance in watts per square meter for local noon. The curves for June have the steepest slopes for all three stations, and the curves for March have the least steep slopes.

Tables 15, 16, and 17 contain frequencies of daily solar energy in watt-hours per square meter for the three stations. A large preponderance of values falls within a small range in June, and the distributions are more spread out in the other months. On more than three-fourths of the June days, the surface receives solar energies greater than 8800 Wh m^{-2}. The corresponding fractions are less than one-fifth for May and July at Riyadh and Dhahran and for May at

Qaisumah. On approximately forty-six percent of the days in July at Qaisumah, the surface receives daily energies of at least 8800 Wh m^{-2}. It follows from these tables that in June one can use climatology to predict the daily solar energy cycle with a high degree of reliability for any given day. In other months there is more variation, and deviations from a typical or average day will often be quite large.

IV. COMPARISON WITH OTHER DATA

Table 18 summarizes mean data from different sources. Means from the ETAC data are among the highest that were found. They are much higher than values from the *Saudi Arabian Solar Radiation Atlas*, (Saudi Arabian National Center for Science and Technology, 1983) for the years 1971-1980. Data in this atlas are based on both measured values and on values computed from sunshine duration. Missing values were filled in with an interpolation procedure based on data at surrounding stations. There is not an indication as to how many observations were missing.

In order to compare simultaneous values, ETAC data were compared with the *Solar Radiation Atlas of Africa* (Raschke et al., 1991) based on satellite radiation measurements. It contains monthly mean daily global and diffuse irradiances for 1985 and 1986 for 2.5° grid intervals for an area which includes Saudi Arabia as well as Africa. Figure 5 compares means computed from ETAC data with values linearly interpolated from the four grid points surrounding Riyadh in the Atlas. It can be seen that ETAC irradiances are higher throughout the two-year period. Figures 6 and 7 for Qaisumah and Dhahran show the same pattern. Figure 7 also has a curve for 1985 at Dhahran based on measurements from Said and Abdelrahman (1989). For most of the year, the measurements of Said and Abdelrahman produce values intermediate between the values from Raschke et al. (1991) and those from the ETAC model.

Raschke et al. (1991) point out that strong regional gradients in atmospheric transmittance are not represented in their simple radiative model. As an example, they consider clear-sky transmittance for 1985 and 1986 for four stations in Jordan. Er Rabbah (31°16'N, 35°45'E, 920 m) and Shoubak (30°31'N 35°32'E, 1395 m) have clear-sky transmittances near 0.80 in winter and 0.70 in summer. At Amman (31°59'N, 35°59'E, 766 m) and Deir Alla (32°13'N, 35°31'E, -224 m) clear-sky transmittances are approximately 0.60 in winter and 0.55 in summer. The scatter diagram in their publication shows very little overlap between the lower set and the higher set of transmittances.

Figure 8 provides additional evidence concerning the reliability of *Solar Radiation Atlas of Africa* (Raschke et al., 1991). Surface measurements from Al-Aruri et al. (1988) for Kuwait (29°20'N, 47°57'E) are compared with values interpolated between grid points in the atlas. The surface measurements produced higher average daily solar energies than those estimated from satellite data.

The characteristic of the ETAC data that means were closer to maxima than to minima was also found in the data for Kuwait from Al-Aruri et al. (1988) and for Dhahran from Elhadidy et al. (1990). In hot weather minima are typically associated with sandstorms. In the cooler part of the year, very low values are likely to be associated with clouds and rainfall. These latter changes are often much more abrupt than the changes associated with sandstorms.

Research quality measurements in Saudi Arabia exist for only short periods. For example, some very careful measurements of solar irradiance in the Rub-al-Khali desert (or Empty Quarter) were made by Smith (1986a,b) as part of an investigation of the surface energy budget. The most measurements were made near Sharouwrah (17°45'N, 47°12'E). The noon maxima appeared to range from 965 to 1070 W m^{-2} according to the small graphical representation of the diurnal variation at Sharouwrah based on 15-minute sampling on 27 days in June 1981. Smith's text lists the mean for noon on these 27 days as 1017 W m^{-2}. In the ETAC data which were serially completed by this office, the noon solar irradiance for Riyadh in 1981 varied from 1019 to 1056 W m^{-2} with a mean of 1052 W m^{-2}. The smaller variation in the ETAC data for Riyadh may be caused by localized differences between the two regions, or it may be that some fluctuations are not represented adequately in the ETAC model which depends upon standard weather data.

The authors did not have adequate data to make a direct comparison of this type of fluctuation between the two regions, but monthly means of total daily solar energy reaching the surface in the two regions can be compared. Interpolation between grid points from Raschke et al. (1991) indicates that Riyadh receives approximately 4 percent and 7 percent more solar energy than Sharouwrah in June 1985 and 1986, respectively. Solar energy received at Riyadh in June during 1971-1980 is approximately 2 percent more than the amount received at Sharouwrah according to interpolation from grid-point data in the *Saudi Arabian Solar Radiation Atlas* (Saudi Arabian National Center for Science and Technology (SANCST), 1983). The mean irradiance of 1052 W m^{-2} for local noon in June 1981 at Riyadh based on the serially completed series of ETAC data is between 3 and 4 percent greater than the corresponding carefully measured mean of 1017 W m^{-2} for Sharouwrah. This would indicate that the data established in this report are within reasonable limits.

Although ETAC did not make details of their model available to the authors, it is known that radiation models have general applicability in many types of climates. For example, Davies and McKay (1989) have evaluated several models by comparison with data from 15 stations, including four Australian, four American, four European, and three Canadian. Australian stations and Albuquerque were relatively cloud-free in this sample. Davies and McKay concluded that, in general, cloud layer models were the most reliable for estimating global irradiance from standard surface meteorological observations. The limited information which ETAC furnished to us indicated that data were required concerning different cloud layers. It is possible that the results would conform more closely to recent urban measurements if albedos for the three sites had been available. Readers interested in radiation models may want to consult Dobesch et al. (1992) to obtain some of the recent references.

In order to agree with most of the recent measurements in urbanized areas, the solar irradiances in this report would need to be reduced by approximately ten percent. The authors did not revise their data to conform more closely with these recent reported measurements for two reasons. First, it is reasonable to expect that the air is clearer at sites far removed from activities of large numbers of people. This belief is not just intuitive but is based on evidence from other geographical areas, particularly the nearby country of Israel, as discussed in Section II.B of this report. Secondly, it is not always realistic to assume that measured solar irradiances are entirely accurate except in carefully conducted research projects. For example, there is no way to know if observers were conscientious in such tasks as keeping dust off instruments. This is especially important under dusty and sandy conditions because a layer of dust on the dome of a pyranometer can significantly impede transfer of solar radiation. This technical report should be useful in spite of some uncertainties if the user keeps in mind that the values are at or near the upper limits to be expected in the region.

V. SUMMARY AND CONCLUSIONS

Hourly solar irradiance data were obtained from the U.S. Air Force Environmental Technical Applications Center (ETAC) for the three Saudi Arabian stations Riyadh, Dhahran, and Qaisumah for the period January 1981 through June 1991. These data were based on a model which used standard meteorological data and an albedo supplied by us. The number of values missing was minimal for three-hourly data until the middle of August 1990 when data became sporadic. Therefore, we used careful interpolation to establish serially complete sets of hourly total solar irradiances only for the period January 1981 through July 1990.

Tables of maximum, minimum, and mean daily totals, mean hourly values, and frequency distributions for noon are included. Comparison of monthly means and extremes with published data did not produce definitive results. Considerable disagreement exists among published amounts of solar radiation reaching the surface in this region. The explanation cannot be decided with certainty. Errors might exist in the measurements themselves if observers took insufficient care to dust and maintain the instruments. It may be that recent rapid urbanization at the sites of the observations has caused pollution which inhibits part of the solar energy from reaching the surface of the earth. Some published analyses of long-term measurements of solar energy reaching the earth in an urbanized part of the nearby country of Israel found a large negative trend which may be the result of increased pollution. Figure 9 shows graphically how our values of daily mean solar energy at the surface compare with other values in the literature. The solar energies estimated in this report agree with the highest published values and should be considered as an upper limit of what is likely to occur in the region.

Table 1. Percent of Solar Irradiance Data Missing from ETAC Data for 1981-90

Hour (UT)	Station	J	F	M	A	M	J	J	A	S	O	N	D
		Month											
3	Riyadh	5.5	2.1	6.1	9.0	5.8	4.3	4.8	10.3	15.0	13.5	5.0	4.2
	Qaisumah	4.8	1.8	4.5	4.7	7.7	8.0	4.5	10.3	16.0	15.2	8.7	6.1
	Dhahran	1.0	0.4	3.5	3.3	3.5	2.3	2.9	8.7	12.7	12.9	9.0	0.6
6	Riyadh	2.6	5.7	4.5	5.0	3.9	2.0	1.9	7.7	12.3	11.3	13.3	11.6
	Qaisumah	2.9	2.5	4.5	3.3	2.3	2.3	1.9	9.7	12.7	10.3	12.0	12.6
	Dhahran	1.6	3.2	3.2	0.3	1.3	0.7	0.6	6.5	10.3	9.4	10.0	10.0
9	Riyadh	4.5	4.3	8.1	7.0	7.7	3.3	5.8	9.7	14.7	12.3	10.3	8.7
	Qaisumah	5.5	5.7	7.1	6.7	7.1	7.7	6.8	9.7	12.7	13.2	8.3	9.0
	Dhahran	1.9	3.9	4.2	2.3	2.6	1.0	0.3	8.4	10.7	10.3	8.0	4.8
12	Riyadh	3.5	2.5	4.2	4.3	3.9	5.0	5.5	12.3	12.7	12.9	13.7	12.9
	Qaisumah	3.9	3.2	3.9	4.7	5.5	9.7	9.4	9.7	12.0	12.9	13.3	13.9
	Dhahran	1.0	0.7	2.9	1.0	1.9	2.3	1.9	6.1	10.3	11.3	11.3	12.6
15	Riyadh	1.0	0.7	10.6	7.0	10.6	7.0	7.7	11.9	6.0	1.3	0.7	0.0
	Qaisumah	1.9	3.9	11.6	6.7	11.3	10.7	13.9	13.5	7.3	3.9	2.0	1.0
	Dhahran	0.3	0.0	2.3	0.3	3.9	2.7	3.5	8.4	0.0	0.6	0.3	0.0

Table 2. Number of Values in ETAC Data for March

Station	Hour (UT)	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	TOTAL
		Year										
Riyadh												
	03	26	27	30	29	31	30	30	29	31	28	291
	04	3	2	8	8	4	3	9	6	6	3	52
	05	9	5	7	7	3	1	8	9	7	5	61
	06	29	31	31	28	30	31	30	28	29	29	296
	07	4	4	9	9	3	1	5	10	8	4	57
	08	3	5	4	9	3	0	5	8	10	2	49
	09	28	30	28	28	30	31	25	29	26	30	285
	10	2	3	4	6	4	0	9	8	5	3	44
	11	1	1	5	4	1	1	7	9	8	1	38
	12	31	29	29	28	31	30	30	30	28	31	297
	13	3	1	5	2	0	5	6	8	7	0	37
	14	4	0	2	2	0	7	7	7	6	2	37
	15	27	29	27	28	29	30	28	26	27	26	277
Qaisumah												
	03	30	30	28	30	31	31	29	30	28	29	296
	04	1	0	1	3	2	2	1	3	2	2	17
	05	0	0	2	2	0	0	1	2	1	0	8
	06	31	31	28	31	31	30	30	30	26	28	296
	07	0	1	1	0	0	1	2	5	0	2	12
	08	0	1	2	2	0	2	4	5	1	0	17
	09	30	30	30	30	28	29	28	29	24	30	288
	10	0	2	2	0	0	2	2	4	0	2	14
	11	0	3	2	0	0	3	4	3	0	4	19
	12	30	31	30	30	30	30	30	29	28	30	298
	13	0	4	1	0	0	1	2	3	0	3	14
	14	1	2	0	1	1	1	3	3	0	4	16
	15	30	30	29	27	29	26	28	26	26	23	274
Dhahran												
	03	29	29	31	31	30	31	31	29	29	29	299
	04	0	3	3	4	1	7	6	1	4	3	32
	05	1	1	3	3	2	3	6	1	6	4	30
	06	31	28	30	31	30	30	30	30	31	29	300
	07	2	3	1	1	2	2	5	2	6	2	26
	08	2	1	1	3	3	3	5	2	5	2	27
	09	28	28	31	30	31	30	31	30	29	29	297
	10	2	2	2	3	3	6	4	2	4	4	32
	11	2	2	2	5	4	5	3	2	4	3	32
	12	30	30	31	31	31	29	31	29	29	30	301
	13	2	1	2	7	2	5	4	2	6	2	33
	14	1	0	3	2	2	4	4	2	3	4	25
	15	31	31	31	31	31	31	30	31	31	25	303

Table 3. Number of Values in ETAC Data for June

Station	Hour (UT)	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	TOTAL
Riyadh												
	03	28	27	30	30	30	29	29	28	29	27	287
	04	18	18	19	26	17	3	14	14	12	11	152
	05	25	19	19	25	13	1	17	15	13	11	158
	06	30	29	30	29	30	30	30	30	28	28	294
	07	15	18	22	20	4	1	15	14	10	7	126
	08	12	15	19	12	5	1	14	13	9	7	107
	09	28	27	30	30	29	30	29	29	29	29	290
	10	5	6	12	11	4	1	15	8	7	5	74
	11	3	7	9	12	4	2	13	4	10	4	68
	12	28	30	30	30	28	29	27	29	28	26	285
	13	6	9	6	10	6	3	12	3	10	5	70
	14	8	9	6	12	7	3	10	4	8	4	71
	15	28	28	28	29	30	29	28	28	26	25	279
Qaisumah												
	03	29	27	29	30	30	28	25	28	27	23	276
	04	1	0	1	2	1	1	4	0	1	3	14
	05	0	0	1	1	0	0	0	0	1	3	6
	06	30	29	29	29	30	30	30	29	29	28	293
	07	3	2	4	2	1	0	6	3	1	5	27
	08	2	1	2	1	0	1	10	5	3	7	32
	09	26	28	27	28	29	29	28	29	26	27	277
	10	4	0	3	1	0	0	8	1	4	10	31
	11	4	1	3	1	1	1	8	3	9	10	41
	12	28	26	26	27	28	28	26	29	27	26	271
	13	2	2	6	0	0	2	8	1	7	8	36
	14	1	0	8	0	0	1	8	2	4	7	31
	15	24	26	27	26	30	28	29	26	27	25	268
Dhahran												
	03	29	29	28	30	30	29	30	30	30	28	293
	04	11	16	22	20	15	8	14	6	15	13	140
	05	22	16	23	23	15	9	18	8	13	14	161
	06	30	30	30	30	30	29	29	30	30	30	298
	07	22	19	21	22	16	7	22	10	15	14	168
	08	20	17	19	24	16	8	21	6	17	13	161
	09	30	28	30	30	30	30	30	29	30	30	297
	10	15	14	17	24	12	10	20	7	11	13	143
	11	13	14	16	22	10	10	18	4	12	11	130
	12	30	29	29	30	30	28	29	28	30	30	293
	13	10	10	11	18	6	7	16	5	10	8	101
	14	8	11	10	20	5	5	15	3	8	7	92
	15	29	29	30	30	30	29	30	29	30	26	292

Table 4. Number of Values in ETAC Data for September

Station	Hour (UT)	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	TOTAL
Riyadh												
	03	29	29	30	28	29	29	27	26	28	0	255
	04	18	18	16	12	9	3	7	10	5	0	98
	05	20	23	24	18	17	6	11	17	5	0	141
	06	29	30	30	28	30	28	28	30	29	1	263
	07	22	18	23	9	7	3	12	6	7	0	107
	08	14	13	18	10	3	2	12	5	6	0	83
	09	27	29	30	29	30	28	30	28	25	0	256
	10	3	2	9	5	0	0	4	2	3	0	28
	11	2	2	6	4	1	0	2	1	3	0	21
	12	28	27	30	30	29	29	30	29	29	1	262
	13	5	1	0	5	1	0	2	4	3	0	21
	14	5	1	1	4	2	1	3	4	1	0	22
	15	29	30	29	29	28	30	28	30	29	20	282
Qaisumah												
	03	29	27	28	30	29	29	27	26	27	0	252
	04	2	0	0	2	0	0	2	1	1	0	8
	05	0	0	0	0	0	0	1	0	3	0	4
	06	29	29	28	30	30	30	28	30	28	0	262
	07	1	2	0	0	1	0	2	0	4	0	10
	08	1	1	0	0	0	0	2	0	3	0	7
	09	30	28	30	29	30	29	30	28	28	0	262
	10	1	1	0	0	1	0	1	0	4	0	8
	11	2	0	0	0	0	0	1	1	5	0	9
	12	27	27	30	29	30	30	30	30	30	1	264
	13	0	1	0	1	1	0	2	1	3	0	9
	14	0	1	0	0	1	0	3	1	3	0	9
	15	30	28	29	28	30	29	29	29	29	17	278
Dhahran												
	03	29	25	29	30	30	30	30	29	30	0	262
	04	13	12	14	15	9	5	12	6	12	0	98
	05	20	14	16	15	8	6	10	5	11	1	106
	06	30	30	30	30	30	30	30	29	30	0	269
	07	18	13	11	15	5	4	8	7	10	0	91
	08	15	10	7	14	3	2	8	4	5	0	68
	09	30	29	29	30	30	30	30	30	30	0	268
	10	6	6	5	11	2	1	7	2	7	0	47
	11	5	5	4	10	4	0	7	5	7	0	47
	12	30	30	30	30	30	29	30	30	30	0	269
	13	7	4	3	7	3	0	7	3	3	0	37
	14	7	5	1	8	2	0	8	2	4	0	37
	15	30	30	30	30	30	30	30	30	30	30	300

Table 5. Number of Values in ETAC Data for December

Station	Hour (UT)	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	TOTAL
Riyadh												
	03	22	31	31	31	31	31	29	30	31	30	297
	04	5	4	2	0	2	4	1	6	3	0	27
	05	7	7	9	0	1	3	4	6	1	0	38
	06	29	31	30	31	29	30	30	28	30	6	274
	07	8	6	4	0	0	4	4	6	0	0	32
	08	8	4	3	1	0	4	4	6	1	0	31
	09	30	31	29	30	29	24	30	29	30	21	283
	10	3	1	3	0	0	2	5	3	0	0	17
	11	2	2	2	1	0	3	8	3	1	0	22
	12	31	31	30	29	31	30	30	28	29	1	270
	13	2	1	1	0	1	2	2	1	0	0	10
	14	6	6	8	5	7	8	9	9	5	6	69
	15	31	31	31	31	31	31	31	31	31	31	310
Qaisumah												
	03	24	29	31	31	31	31	29	31	25	29	291
	04	0	0	2	1	1	1	0	2	1	0	8
	05	0	1	0	0	0	0	1	1	0	0	3
	06	29	29	31	31	28	28	30	30	29	6	271
	07	0	1	1	0	2	1	1	0	1	0	7
	08	0	0	3	0	1	1	2	2	2	0	11
	09	29	28	31	29	30	28	31	29	28	19	282
	10	0	1	3	0	1	0	2	2	0	1	10
	11	1	1	1	0	1	3	5	2	0	0	14
	12	30	30	28	31	30	29	29	30	30	0	267
	13	0	1	3	0	2	2	1	1	1	0	11
	14	7	13	16	0	12	15	14	13	15	16	121
	15	31	31	31	31	31	31	29	30	31	31	307
Dhahran												
	03	31	30	31	31	31	31	30	31	31	31	308
	04	3	5	2	0	3	2	2	0	4	0	21
	05	4	7	2	2	2	3	3	1	5	0	29
	06	31	31	31	31	31	29	29	31	30	5	279
	07	4	4	3	3	1	3	1	0	3	0	22
	08	6	2	2	2	0	4	2	2	2	0	22
	09	29	31	31	31	31	28	31	31	31	21	295
	10	2	2	1	0	3	1	1	3	1	0	14
	11	0	2	2	0	4	3	2	3	1	0	17
	12	27	31	31	31	31	29	31	31	29	0	271
	13	1	2	0	0	2	3	1	1	1	0	11
	14	27	30	30	29	29	28	30	29	29	28	289
	15	31	31	31	31	31	31	31	31	31	31	310

Table 6. Daily Solar Energy (Wh m^{-2}) by Year from ETAC Data for Riyadh

Year	Statistic	Month											
		J	F	M	A	M	J	J	A	S	O	N	D
81	Max	5163	6723	7785	8394	8799	8885	8833	8553	8017	7152	5957	4900
81	Mean	4439	5636	6276	7524	7827	8805	8498	8197	7579	6351	4962	4395
81	Min	3609	4103	2000	5507	3499	8564	7785	7430	6955	5220	2910	2941
82	Max	5418	6682	7487	8436	8715	8886	8834	8538	7991	7134	5378	4833
82	Mean	4446	5147	5650	6803	7289	8756	8698	8237	7506	5603	4239	3916
82	Min	2649	2479	3360	3569	3655	7757	8396	7533	7073	3433	2318	1764
83	Max	5480	6810	7352	8245	8683	8878	8816	8550	8020	7191	5987	4891
83	Mean	4486	5689	6415	6885	6871	8474	8517	7671	7637	6603	5236	4411
83	Min	1796	3755	4018	4532	5028	5861	6965	5381	7126	6026	3255	3047
84	Max	5623	6633	7736	8378	8809	8883	8803	8526	8030	7137	5677	4893
84	Mean	4913	5812	6559	7319	7968	8827	8401	8239	7470	6480	4564	3613
84	Min	2716	2762	3759	3719	5377	8502	6795	7121	6819	4798	3230	1670
85	Max	5290	6841	7493	8353	8799	8884	8844	8581	7993	7152	5809	4860
85	Mean	4268	6099	5900	7102	7267	8816	8567	7968	7394	6567	4710	3846
85	Min	2004	4605	3711	4538	4032	8262	7327	6645	5864	5201	3306	1515
86	Max	5502	6784	7579	8374	8795	8888	8839	8570	8025	7180	5965	4874
86	Mean	4690	5772	6573	6516	8138	8701	8485	8192	7536	6445	4886	4197
86	Min	2240	4133	3287	2415	6815	8122	6438	7057	6702	4354	3511	1856
87	Max	5672	6681	7715	8432	8726	8880	8839	8362	8075	7187	5790	4906
87	Mean	4993	5890	6130	7742	7466	8821	8582	8056	7613	6233	5254	4342
87	Min	3886	4544	2966	5382	4380	8617	7446	6630	7219	4843	4439	2621
88	Max	5625	6786	7762	8461	8859	8884	8835	8542	8056	7138	5957	4873
88	Mean	4569	5329	6907	6901	8418	8761	8359	8039	7534	6501	5215	4214
88	Min	1891	3508	4644	4767	6532	7901	6523	6470	6708	5390	4636	3156
89	Max	5578	6856	7769	8425	8804	8893	8837	8541	8060	7169	5914	4827
89	Mean	4734	5477	6568	6495	8432	8791	8527	8097	7533	6548	4632	4088
89	Min	2955	1645	4633	3453	6942	8141	7766	5192	7100	5095	3095	2016
90	Max	5641	6820	7286	8243	8806	8894	8824					
90	Mean	4410	5526	6198	7215	8191	8833	8528					
90	Min	2516	2441	3615	3936	5588	8083	7019					

Table 7. Daily Solar Energy (Wh m^{-2}) by Year from ETAC Data for Qaisumah

Year	Statistic	Month											
		J	F	M	A	M	J	J	A	S	O	N	D
81	Max	5305	6373	7708	8242	8886	8946	8931	8573	7954	6889	5528	4318
81	Mean	3690	4606	6057	7448	7906	8896	8634	8192	7382	5823	4493	3741
81	Min	1732	1653	2876	5273	3496	8419	7221	7484	6234	3846	2346	2186
82	Max	4992	6480	7706	8414	8812	8946	8931	8579	7945	6531	5303	4387
82	Mean	3870	4890	5688	6488	7197	8780	8799	8287	7195	5346	4366	3651
82	Min	1630	1749	3172	3583	4464	7267	8594	7809	6102	3291	2867	2125
83	Max	5197	6444	7683	8362	8878	8942	8915	8578	7952	6899	5506	4312
83	Mean	3718	5299	6428	6913	7456	8466	8744	8037	7467	6239	4581	3690
83	Min	2111	3441	4397	3908	4948	5014	7971	6168	6945	5592	2400	2497
84	Max	5187	6187	7038	8407	8877	8947	8920	8570	7930	6834	4955	4310
84	Mean	4053	4908	5513	7265	7653	8915	8676	8283	7260	5786	3925	3479
84	Min	2657	2928	2977	4714	5417	8544	7684	7963	6232	3446	2347	2266
85	Max	4510	6466	7603	8411	8886	8946	8931	8556	7942	6889	4984	4414
85	Mean	3524	5454	5685	7159	7477	8930	8628	8163	7379	6138	3791	3408
85	Min	1711	4067	2944	4493	5034	8864	5595	7353	6069	4403	2144	1673
86	Max	4871	6295	7347	8288	8817	8944	8928	8563	7939	6684	5535	4363
86	Mean	3933	5294	6286	6605	7266	8610	8644	8108	7355	5948	4163	3709
86	Min	2272	3273	4150	4764	4872	6926	7232	6694	6544	3570	2574	2099
87	Max	5197	6398	7348	8191	8584	8951	8937	8424	7950	6904	5236	4271
87	Mean	4458	5339	5976	6937	7117	8867	8714	8201	7438	5010	4479	3760
87	Min	3547	3463	2800	4740	4535	7885	7754	7856	6714	3235	3135	2359
88	Max	5187	5994	7324	8370	8877	8946	8928	8557	7870	6878	5306	4354
88	Mean	4130	5005	6107	6901	8099	8762	8408	8150	7344	5573	4305	3243
88	Min	2336	3355	3365	5009	6605	7777	6678	6477	6188	2977	3010	1789
89	Max	5135	6327	7694	8180	8899	8956	8926	8573	7935	6910	5158	4321
89	Mean	4130	5102	6222	6951	7340	8911	8650	8219	7288	6016	3985	3826
89	Min	2859	3181	3643	4678	4505	8576	6814	7416	6300	4098	2338	2335
90	Max	5013	6455	7600	8217	8874	8948	8931					
90	Mean	3903	5393	6334	7271	8498	8926	8696					
90	Min	2612	3339	4610	5335	6391	8879	7813					

Table 8. Daily Solar Energy (Wh m^{-2}) by Year from ETAC Data for Dhahran

Year	Statistic	J	F	M	A	M	J	J	A	S	O	N	D
		Month											
81	Max	5190	6632	7794	8176	8942	8926	8877	8525	7923	7024	5813	4664
81	Mean	4249	5375	6325	7281	7865	8874	8622	8172	7495	6181	4906	4234
81	Min	1729	3640	3804	5720	4961	8791	7865	7383	7055	5481	3580	3202
82	Max	5181	6649	7452	8283	8842	8941	8851	8544	7918	7076	5447	4628
82	Mean	4561	5249	5789	6966	7663	8815	8732	8108	7398	5868	4487	3995
82	Min	3826	2248	2765	4386	5647	7096	8478	6350	6554	4148	2216	1930
83	Max	5291	6523	7648	8026	8657	8935	8853	8511	7968	7053	5826	4590
83	Mean	4381	5494	6424	6762	7178	8741	8531	8000	7548	6400	5105	4162
83	Min	3017	3189	2905	3149	4220	7343	6886	6509	7027	5773	3926	3017
84	Max	5400	6413	7109	8216	8860	8913	8873	8567	7924	7041	5080	4644
84	Mean	4697	5584	5974	7180	7983	8724	8587	8210	7454	6300	4438	3744
84	Min	2850	3508	3047	3705	4752	6457	7246	7214	6827	4680	2294	1704
85	Max	5335	6600	7754	8146	8899	8923	8871	8445	7929	7035	5448	4705
85	Mean	4225	5893	5875	7184	7449	8877	8241	7930	7513	6366	4763	3732
85	Min	2131	4003	3526	4904	3985	8702	5873	5685	7059	5203	3286	2149
86	Max	5271	6428	7609	8059	8854	8911	8851	8561	7849	7040	5761	4645
86	Mean	4503	5538	6431	6592	7821	8666	8587	7882	7414	6237	4702	3796
86	Min	2171	3544	3400	3998	5350	6266	6159	4699	6875	3795	3069	1757
87	Max	5484	6470	7553	8378	8761	8923	8874	8558	7962	7031	5608	4604
87	Mean	4668	5407	6024	7413	7478	8707	8571	8094	7534	6077	5138	4114
87	Min	2518	3259	3281	5022	3587	7031	6133	6954	7058	4992	4325	3160
88	Max	5323	6423	7729	8235	8902	8937	8803	8501	7827	7031	5741	4649
88	Mean	4445	5345	6702	7109	8446	8814	8259	8133	7386	6235	4997	4005
88	Min	3366	4220	5095	5678	7634	8271	6572	7240	7049	4943	4165	3197
89	Max	5255	6642	7804	8173	8900	8927	8878	8557	7931	7035	5580	4654
89	Mean	4738	5469	6663	7172	8420	8832	8455	8076	7524	6349	4673	4135
89	Min	3672	3994	4518	4952	6957	8350	7454	7558	7057	5280	3642	2260
90	Max	5380	6677	7723	8134	8927	8927	8860					
90	Mean	4394	5492	6675	7401	8252	8867	8561					
90	Min	1884	3896	5256	6511	5066	8709	7776					

Table 9. Mean and Extreme Hourly Solar Irradiance (W m^{-2}) from ETAC Data for Riyadh

Statistic	Hour (UT)	J	F	M	A	M	J	J	A	S	O	N	D
Maximum	02	0	0	0	0	0	0	0	0	0	0	0	0
	03	0	0	33	135	175	173	131	76	51	42	10	0
	04	39	125	277	395	455	450	380	342	318	274	205	98
	05	264	382	540	644	687	679	614	585	564	534	448	320
	06	470	601	755	847	862	855	816	779	767	744	659	526
	07	669	792	914	980	989	982	953	931	920	889	802	677
	08	798	910	1005	1050	1054	1049	1032	1020	1007	968	872	762
	09	854	956	1029	1055	1057	1056	1052	1049	1030	976	873	777
	10	838	935	993	1010	1017	1028	1033	1032	999	920	787	731
	11	748	843	890	904	921	944	954	952	902	796	641	626
	12	587	678	715	728	762	805	816	811	738	599	449	455
	13	355	454	508	487	549	627	622	605	518	372	232	237
	14	120	187	257	238	312	396	385	356	255	107	11	39
	15	0	0	2	18	66	117	124	107	26	0	0	0
Mean	02	0	0	0	0	0	0	0	0	0	0	0	0
	03	0	0	4	69	136	151	93	54	43	26	1	0
	04	22	65	175	304	375	399	321	283	282	232	128	40
	05	205	275	396	525	594	635	559	526	533	475	344	222
	06	383	469	586	699	772	831	774	745	745	676	523	391
	07	546	641	744	834	895	962	919	898	895	819	661	535
	08	662	762	844	904	959	1034	1007	989	980	895	739	631
	09	716	822	884	914	967	1048	1036	1019	1000	902	749	663
	10	693	808	852	868	917	1011	1014	993	949	825	675	616
	11	607	725	752	765	813	918	933	904	834	688	544	509
	12	459	573	597	610	661	772	793	753	660	500	370	351
	13	260	369	352	384	442	570	597	549	434	285	120	154
	14	42	129	131	169	224	336	360	301	176	48	2	3
	15	0	0	0	6	33	91	113	64	4	0	0	0
Minimum	02	0	0	0	0	0	0	0	0	0	0	0	0
	03	0	0	0	12	49	87	41	21	19	6	0	0
	04	9	10	47	102	166	252	128	134	179	106	28	7
	05	58	61	109	161	248	403	178	253	337	210	85	53
	06	101	106	161	198	218	535	196	373	465	296	132	98
	07	190	156	253	239	326	624	563	506	647	358	290	188
	08	271	195	268	263	430	677	672	563	791	389	323	203
	09	295	217	261	271	420	692	664	510	776	391	314	177
	10	276	207	246	304	393	629	662	587	723	466	334	204
	11	208	180	214	291	344	425	619	462	624	329	292	197
	12	134	138	163	176	278	420	512	327	485	189	198	84
	13	81	84	76	126	188	288	338	329	294	108	51	32
	14	9	22	18	53	90	156	145	190	66	10	0	0
	15	0	0	0	0	6	32	23	17	0	0	0	0

Table 10. Mean and Extreme Hourly Solar Irradiance (W m^{-2}) from ETAC Data for Qaisumah

Statistic	Hour (UT)	J	F	M	A	M	J	J	A	S	O	N	D
Maximum	02	0	0	0	0	6	6	0	0	0	0	0	0
	03	0	0	29	137	182	182	142	81	49	30	0	0
	04	15	96	269	404	450	445	381	331	319	253	170	52
	05	226	344	518	643	678	670	608	567	559	500	400	264
	06	418	557	729	832	853	849	812	769	743	705	606	464
	07	612	747	884	964	978	975	945	919	895	852	746	612
	08	743	867	978	1036	1045	1043	1026	1008	983	931	821	699
	09	801	917	1006	1044	1052	1052	1049	1040	1012	943	825	718
	10	788	896	966	995	1017	1028	1030	1025	981	887	751	673
	11	703	807	866	889	925	949	955	949	888	769	602	574
	12	547	649	704	732	773	816	824	814	734	581	419	411
	13	336	436	507	538	560	628	646	617	522	363	218	208
	14	116	178	260	295	323	401	420	381	265	107	7	8
	15	0	0	10	35	91	146	152	131	38	0	0	0
Mean	02	0	0	0	0	0	0	0	0	0	0	0	0
	03	0	0	3	66	139	163	105	59	38	13	0	0
	04	4	41	154	292	368	407	330	297	274	195	82	15
	05	162	240	364	503	573	631	558	531	517	423	283	179
	06	319	420	542	671	740	824	775	745	714	612	456	336
	07	467	582	693	801	860	953	916	891	861	747	584	475
	08	575	701	796	879	925	1026	1005	984	949	821	660	568
	09	631	763	842	900	933	1041	1037	1018	972	827	674	604
	10	614	745	803	861	893	1009	1019	995	926	754	600	558
	11	532	664	707	764	796	922	942	911	818	624	475	455
	12	396	525	560	617	655	783	810	769	652	449	314	306
	13	217	336	384	417	439	578	624	569	434	256	103	114
	14	26	111	180	207	231	351	397	326	183	42	1	0
	15	0	0	3	16	49	118	143	85	7	0	0	0
Minimum	02	0	0	0	0	0	0	0	0	0	0	0	0
	03	0	0	0	12	26	99	36	28	16	0	0	0
	04	0	7	45	69	92	289	156	175	141	96	25	2
	05	40	54	105	132	154	414	312	390	258	213	92	74
	06	79	96	155	183	210	498	488	568	353	212	140	145
	07	185	161	279	374	248	541	586	710	556	357	289	213
	08	200	209	378	414	272	545	642	639	644	388	257	256
	09	193	200	390	426	280	515	662	479	490	309	195	275
	10	230	238	343	409	419	494	652	652	638	315	250	242
	11	218	235	254	357	375	446	605	586	680	269	204	188
	12	153	147	152	256	179	374	516	458	490	189	122	120
	13	76	97	104	165	109	277	394	364	223	111	26	29
	14	1	34	38	65	49	167	247	229	51	5	0	0
	15	0	0	0	3	6	41	57	30	0	0	0	0

Table 11. Mean and Extreme Hourly Solar Irradiance (W m^{-2}) from ETAC Data for Dhahran

Statistic	Hour (UT)	J	F	M	A	M	J	J	A	S	O	N	D
Maximum	02	0	0	0	2	34	34	9	0	0	0	0	0
	03	0	0	76	192	234	233	187	125	95	81	39	0
	04	79	182	339	469	489	486	431	365	379	330	247	133
	05	305	430	588	701	720	716	669	616	616	575	483	350
	06	500	637	792	879	894	889	853	818	801	770	679	542
	07	675	811	934	998	1007	1002	975	953	938	900	805	676
	08	787	910	1007	1054	1059	1056	1042	1028	1010	962	859	745
	09	835	941	1017	1045	1050	1050	1050	1045	1020	955	843	745
	10	800	903	966	987	999	1014	1018	1013	973	884	755	689
	11	695	795	847	867	891	919	927	922	863	744	598	570
	12	521	615	657	677	719	766	776	768	685	535	379	387
	13	280	383	440	452	546	564	578	555	458	303	163	166
	14	71	126	185	205	312	324	338	299	192	49	0	0
	15	0	0	0	0	36	82	88	71	0	0	0	0
Mean	02	0	0	0	0	2	10	0	0	0	0	0	0
	03	0	0	19	110	193	209	144	98	85	60	11	0
	04	51	105	225	352	429	450	370	325	336	282	169	70
	05	239	313	434	570	647	679	604	565	578	520	383	257
	06	411	498	603	746	825	865	813	782	777	708	557	421
	07	564	659	746	865	931	980	942	919	914	833	679	551
	08	668	769	838	925	981	1039	1015	997	983	891	739	627
	09	711	815	869	922	972	1042	1032	1015	985	878	733	640
	10	670	777	819	861	904	998	998	979	922	785	634	576
	11	565	673	708	744	784	895	904	880	795	633	485	455
	12	401	510	546	581	619	737	753	722	609	436	301	289
	13	197	300	353	321	385	532	551	504	377	186	112	105
	14	8	64	129	107	172	294	310	249	114	11	0	0
	15	0	0	0	0	11	60	79	34	0	0	0	0
Minimum	02	0	0	0	0	0	1	0	0	0	0	0	0
	03	0	0	0	18	72	96	67	42	38	21	0	0
	04	21	38	64	110	164	272	174	150	224	161	54	12
	05	101	125	125	228	238	379	290	268	383	308	108	57
	06	172	198	175	293	295	427	406	389	383	428	152	96
	07	238	271	218	368	424	538	602	456	608	527	228	203
	08	253	325	247	424	465	629	651	496	828	497	291	265
	09	204	355	259	411	453	664	662	505	720	396	259	176
	10	235	328	341	369	406	637	652	589	740	458	287	241
	11	206	275	292	261	340	527	600	617	691	380	221	181
	12	148	201	223	158	221	305	485	469	492	252	134	68
	13	62	114	144	72	104	292	351	332	280	59	31	24
	14	0	11	44	17	26	201	190	168	43	0	0	0
	15	0	0	0	0	0	27	40	0	0	0	0	0

Table 12. Frequency Distribution of 0900 UTC (Noon Local Standard Time) Solar Irradiance (W m^{-2}) from ETAC Data for Riyadh

Range	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
170-179	0	0	0	0	0	0	0	0	0	0	0	1
180-189	0	0	0	0	0	0	0	0	0	0	0	1
190-199	0	0	0	0	0	0	0	0	0	0	0	0
200-209	0	0	0	0	0	0	0	0	0	0	0	0
210-219	0	1	0	0	0	0	0	0	0	0	0	0
220-229	0	1	0	0	0	0	0	0	0	0	0	0
230-239	0	0	0	0	0	0	0	0	0	0	0	0
240-249	0	0	0	0	0	0	0	0	0	0	0	2
250-259	0	0	0	0	0	0	0	0	0	0	0	1
260-269	0	0	1	0	0	0	0	0	0	0	0	0
270-279	0	0	0	1	0	0	0	0	0	0	0	0
280-289	0	0	0	1	0	0	0	0	0	0	0	1
290-299	1	0	0	0	0	0	0	0	0	0	0	0
300-309	1	0	0	0	0	0	0	0	0	0	0	1
310-319	1	0	0	0	0	0	0	0	0	0	1	2
320-329	1	1	0	0	0	0	0	0	0	0	0	5
330-339	0	0	1	0	0	0	0	0	0	0	1	1
340-349	1	0	0	0	0	0	0	0	0	0	0	0
350-359	2	1	0	0	0	0	0	0	0	0	1	0
360-369	2	0	0	0	0	0	0	0	0	0	3	3
370-379	3	1	0	1	0	0	0	0	0	0	1	0
380-389	0	0	0	0	0	0	0	0	0	0	0	0
390-399	1	1	0	1	0	0	0	0	0	1	0	0
400-409	3	0	0	0	0	0	0	0	0	0	0	0
410-419	1	1	1	3	0	0	0	0	0	0	2	0
420-429	0	1	1	1	1	0	0	0	0	0	1	0
430-439	0	0	2	0	0	0	0	0	0	0	0	0
440-449	0	0	3	3	2	0	0	0	0	0	0	4
450-459	1	1	0	0	0	0	0	0	0	0	1	1
460-469	0	0	0	5	1	0	0	0	0	0	1	5
470-479	2	0	0	2	7	0	0	0	0	0	0	8
480-489	3	1	0	1	0	0	0	0	0	0	1	4
490-499	2	0	4	0	0	0	0	0	0	0	4	1
500-509	6	2	3	1	0	0	0	0	0	0	1	1
510-519	1	0	0	4	4	0	0	1	0	0	1	0
520-529	2	0	0	0	0	0	0	0	0	0	1	0
530-539	6	1	1	0	0	0	0	0	0	0	1	0
540-549	3	2	1	0	0	0	0	0	0	0	2	2
550-559	0	1	0	1	0	0	0	0	0	0	2	2
560-569	2	2	0	0	0	0	0	0	0	0	1	13
570-579	0	2	0	1	0	0	0	0	0	2	5	3
580-589	5	3	0	0	1	0	0	1	0	1	2	0
590-599	4	1	0	0	3	0	0	0	0	1	0	3
600-609	2	1	2	1	0	0	0	0	0	1	2	3
610-619	4	2	5	0	0	0	0	0	0	1	1	7

Table 12. Frequency Distribution of 0900 UTC (Noon Local Standard Time) Solar Irradiance (W m^{-2}) from ETAC Data for Riyadh (Continued)

Range	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
620-629	4	1	3	1	0	0	0	0	0	1	2	7
630-639	1	1	4	1	2	0	0	0	0	0	1	3
640-649	2	1	3	1	4	0	0	0	0	0	5	5
650-659	4	5	3	1	2	0	0	0	0	0	2	6
660-669	11	2	4	5	3	0	1	3	0	0	2	6
670-679	4	0	2	3	0	0	0	0	0	0	2	10
680-689	2	3	1	8	2	0	0	2	0	0	2	5
690-699	6	1	1	4	1	3	0	0	0	1	4	6
700-709	3	1	0	1	1	0	0	0	0	0	4	6
710-719	9	2	1	2	1	0	0	0	0	0	10	11
720-729	11	8	1	0	0	0	0	0	0	0	5	0
730-739	7	2	7	1	0	0	0	0	0	4	3	13
740-749	9	1	4	0	0	0	1	0	0	0	11	0
750-759	4	4	4	0	0	0	0	0	0	3	9	60
760-769	17	6	5	1	0	0	0	1	0	1	10	53
770-779	31	5	1	1	0	0	0	0	1	1	7	13
780-789	24	2	3	3	3	0	1	1	0	2	17	0
790-799	18	7	6	2	1	0	1	0	0	0	27	0
800-809	22	11	2	3	7	0	0	1	0	5	19	0
810-819	13	6	2	7	1	0	1	0	0	0	18	0
820-829	18	7	1	1	1	0	0	0	0	1	18	0
830-839	16	5	4	2	0	0	0	1	0	6	13	0
840-849	9	5	4	0	1	0	0	0	0	1	16	0
850-859	5	13	3	0	0	0	0	0	0	3	10	0
860-869	0	19	5	1	1	0	0	1	1	4	13	0
870-879	0	15	6	4	1	0	0	0	0	16	4	0
880-889	0	14	3	6	3	0	4	1	1	23	0	0
890-899	0	15	7	4	6	0	0	1	0	24	0	0
900-909	0	21	9	4	8	0	1	0	0	17	0	0
910-919	0	19	4	3	0	0	0	0	1	21	0	0
920-929	0	15	3	3	1	0	0	0	1	18	0	0
930-939	0	12	7	11	4	0	0	1	4	22	0	0
940-949	0	14	4	4	3	0	1	4	4	23	0	0
950-959	0	12	10	6	12	0	5	1	4	31	0	0
960-969	0	0	19	5	0	0	0	2	1	28	0	0
970-979	0	0	20	7	2	0	3	2	17	16	0	0
980-989	0	0	25	10	6	1	8	9	41	0	0	0
990-999	0	0	20	13	16	3	8	2	40	0	0	0
1000-1009	0	0	27	5	0	0	0	10	37	0	0	0
1010-1019	0	0	22	8	6	4	16	3	51	0	0	0
1020-1029	0	0	25	5	4	4	2	0	62	0	0	0
1030-1039	0	0	0	28	3	2	5	82	4	0	0	0
1040-1049	0	0	0	45	4	0	19	149	0	0	0	0
1050-1059	0	0	0	53	181	283	233	0	0	0	0	0

Table 13. Frequency Distribution of 0900 UTC (Noon Local Standard Time) Solar Irradiance (W m^{-2}) from ETAC Data for Qaisumah

Range	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
170-179	0	0	0	0	0	0	0	0	0	0	0	0
180-189	0	0	0	0	0	0	0	0	0	0	0	0
190-199	1	0	0	0	0	0	0	0	0	0	1	0
200-209	0	2	0	0	0	0	0	0	0	0	0	0
210-219	0	0	0	0	0	0	0	0	0	0	0	0
220-229	0	0	0	0	0	0	0	0	0	0	0	0
230-239	0	0	0	0	0	0	0	0	0	0	0	0
240-249	0	0	0	0	0	0	0	0	0	0	0	0
250-259	1	0	0	0	0	0	0	0	0	0	0	0
260-269	0	0	0	0	0	0	0	0	0	0	0	0
270-279	0	1	0	0	0	0	0	0	0	0	1	2
280-289	2	0	0	0	1	0	0	0	0	0	0	0
290-299	2	0	0	0	0	0	0	0	0	0	0	1
300-309	2	0	0	0	0	0	0	0	0	1	1	1
310-319	4	0	0	0	0	0	0	0	0	0	0	0
320-329	3	0	0	0	0	0	0	0	0	0	1	0
330-339	4	1	0	0	0	0	0	0	0	0	0	9
340-349	2	1	0	0	0	0	0	0	0	0	3	0
350-359	1	0	0	0	0	0	0	0	0	0	0	0
360-369	0	0	0	0	0	0	0	0	0	0	1	0
370-379	4	2	0	0	0	0	0	0	0	0	0	1
380-389	0	1	0	0	0	0	0	0	0	1	1	1
390-399	0	4	1	0	0	0	0	0	0	1	0	1
400-409	0	2	3	0	0	0	0	0	0	1	1	0
410-419	1	0	1	0	0	0	0	0	0	0	0	2
420-429	2	1	2	1	0	0	0	0	0	1	1	7
430-439	1	4	2	2	0	0	0	0	0	0	1	10
440-449	8	2	0	2	1	0	0	0	0	0	4	11
450-459	4	0	2	4	0	0	0	0	0	0	1	5
460-469	8	0	2	0	1	0	0	0	0	0	7	1
470-479	5	0	3	0	0	0	0	1	0	0	8	2
480-489	6	0	4	0	0	0	0	0	0	0	3	3
490-499	1	0	0	2	0	0	0	0	1	0	0	0
500-509	3	2	0	6	0	0	0	0	0	0	0	2
510-519	6	3	1	2	14	2	0	0	0	1	4	6
520-529	6	1	0	0	0	0	0	0	0	1	1	3
530-539	2	4	0	0	0	0	0	0	0	1	7	5
540-549	5	2	0	0	0	0	0	0	0	3	1	4
550-559	5	4	1	0	0	0	0	0	0	0	3	3
560-569	3	5	0	0	0	0	0	0	0	1	1	5
570-579	4	5	0	0	0	0	0	0	0	3	1	5
580-589	4	2	5	0	0	0	0	0	0	1	3	10
590-599	4	1	7	0	0	0	0	0	0	1	3	5
600-609	3	1	7	0	0	0	0	0	0	1	2	3
610-619	7	1	3	0	0	0	0	0	0	2	4	9

Table 13. Frequency Distribution of 0900 UTC (Noon Local Standard Time) Solar Irradiance (W m^{-2}) from ETAC Data for Qaisumah (Continued)

Range	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
620-629	2	1	7	2	1	0	0	0	0	5	6	5
630-639	2	4	5	4	1	0	0	0	0	2	5	5
640-649	4	1	3	3	1	0	0	0	0	0	4	8
650-659	7	0	5	11	5	0	0	0	0	1	7	11
660-669	7	2	0	4	26	1	2	0	0	0	7	11
670-679	10	4	1	10	0	0	0	0	0	3	7	11
680-689	8	3	0	2	7	0	0	0	0	0	13	0
690-699	10	2	4	0	0	0	0	0	0	3	8	61
700-709	14	2	1	0	0	0	0	0	0	2	5	40
710-719	29	1	4	0	0	0	0	0	0	4	14	10
720-729	14	2	0	0	0	0	0	0	0	5	14	0
730-739	20	3	2	1	0	0	0	0	0	3	21	0
740-749	21	5	0	1	0	0	0	0	0	1	12	0
750-759	13	5	2	1	0	0	0	2	1	5	11	0
760-769	11	3	3	1	0	0	0	0	0	2	13	0
770-779	9	2	2	2	1	1	0	0	0	3	10	0
780-789	5	6	5	9	1	0	0	0	0	10	12	0
790-799	9	2	2	3	3	0	2	1	0	5	13	0
800-809	1	19	2	3	1	0	0	0	0	6	12	0
810-819	0	24	1	1	5	0	0	0	0	5	7	0
820-829	0	16	1	0	1	0	0	0	0	11	4	0
830-839	0	12	4	0	0	0	0	0	0	12	0	0
840-849	0	15	4	1	1	0	0	0	2	19	0	0
850-859	0	16	6	4	1	0	0	0	1	14	0	0
860-869	0	18	8	8	1	0	0	0	1	16	0	0
870-879	0	18	7	3	0	1	1	2	0	11	0	0
880-889	0	10	9	6	8	1	0	0	1	15	0	0
890-899	0	12	7	3	3	0	1	0	0	14	0	0
900-909	0	8	7	3	2	2	0	0	4	15	0	0
910-919	0	14	9	7	0	0	0	1	2	18	0	0
920-929	0	0	23	7	3	0	0	0	6	19	0	0
930-939	0	0	16	8	3	0	0	1	3	21	0	0
940-949	0	0	18	4	11	0	2	1	19	9	0	0
950-959	0	0	19	2	10	3	0	0	31	0	0	0
960-969	0	0	15	9	0	0	0	5	30	0	0	0
970-979	0	0	22	11	6	0	2	2	38	0	0	0
980-989	0	0	14	7	15	2	3	2	40	0	0	0
990-999	0	0	16	3	5	0	0	4	35	0	0	0
1000-1009	0	0	12	21	6	0	9	7	43	0	0	0
1010-1019	0	0	0	32	8	5	1	51	12	0	0	0
1020-1029	0	0	0	28	2	0	3	83	0	0	0	0
1030-1039	0	0	0	36	4	0	0	105	0	0	0	0
1040-1049	0	0	0	20	56	28	284	11	0	0	0	0
1050-1059	0	0	0	0	95	254	0	0	0	0	0	0

Table 14. Frequency Distribution of 0900 UTC (Noon Local Standard Time) Solar Irradiance (W m^{-2}) from ETAC Data for Dhahran

Range	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
170-179	0	0	0	0	0	0	0	0	0	0	0	1
180-189	0	0	0	0	0	0	0	0	0	0	0	0
190-199	0	0	0	0	0	0	0	0	0	0	0	0
200-209	1	0	0	0	0	0	0	0	0	0	0	0
210-219	0	0	0	0	0	0	0	0	0	0	0	0
220-229	0	0	0	0	0	0	0	0	0	0	0	0
230-239	1	0	0	0	0	0	0	0	0	0	0	0
240-249	0	0	0	0	0	0	0	0	0	0	0	0
250-259	0	0	1	0	0	0	0	0	0	0	1	0
260-269	0	0	1	0	0	0	0	0	0	0	0	0
270-279	0	0	0	0	0	0	0	0	0	0	0	1
280-289	0	0	0	0	0	0	0	0	0	0	0	4
290-299	1	0	0	0	0	0	0	0	0	0	0	2
300-309	1	0	0	0	0	0	0	0	0	0	0	1
310-319	0	0	0	0	0	0	0	0	0	0	0	1
320-329	1	0	0	0	0	0	0	0	0	0	0	0
330-339	1	0	0	0	0	0	0	0	0	0	1	0
340-349	2	0	0	0	0	0	0	0	0	0	1	0
350-359	1	1	0	0	0	0	0	0	0	0	0	0
360-369	0	1	1	0	0	0	0	0	0	0	1	0
370-379	0	0	0	0	0	0	0	0	0	0	0	0
380-389	0	1	0	0	0	0	0	0	0	0	0	0
390-399	0	1	0	0	0	0	0	0	0	1	0	0
400-409	0	0	3	0	0	0	0	0	0	0	0	0
410-419	0	0	1	1	0	0	0	0	0	0	0	1
420-429	0	1	1	1	0	0	0	0	0	0	0	0
430-439	0	0	1	0	0	0	0	0	0	0	0	1
440-449	0	0	2	1	0	0	0	0	0	0	0	4
450-459	1	0	2	2	1	0	0	0	0	0	0	4
460-469	0	0	0	1	1	0	0	0	0	0	1	3
470-479	1	0	0	0	0	0	0	0	0	0	2	4
480-489	3	0	1	0	0	0	0	0	0	0	2	2
490-499	1	0	0	0	0	0	0	0	0	0	2	1
500-509	2	1	0	2	0	0	0	2	0	0	0	0
510-519	4	0	0	0	4	0	0	0	0	0	0	2
520-529	0	0	0	0	0	0	0	0	0	0	1	5
530-539	0	3	0	0	0	0	0	0	0	0	0	3
540-549	3	1	0	0	0	0	0	0	0	0	0	6
550-559	2	4	0	1	0	0	0	0	0	2	2	2
560-569	0	1	0	0	0	0	0	0	0	0	1	4
570-579	1	1	1	0	0	0	0	0	0	2	1	3
580-589	4	1	0	1	0	0	0	0	0	0	0	5
590-599	2	1	0	2	0	0	0	0	0	0	1	5
600-609	2	2	1	0	1	0	0	0	0	0	0	3
610-619	1	2	1	0	0	0	0	0	0	0	4	12

Table 14. Frequency Distribution of 0900 UTC (Noon Local Standard Time) Solar Irradiance (W m^{-2}) from ETAC Data for Dhahran (Continued)

Range	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
620-629	5	0	8	2	0	0	0	0	0	1	3	8
630-639	7	4	7	2	2	0	0	0	0	0	4	7
640-649	3	1	3	1	1	0	0	0	0	0	7	15
650-659	5	2	1	7	1	0	0	0	0	0	1	14
660-669	8	0	2	4	14	2	4	0	0	1	3	18
670-679	9	3	1	4	0	0	0	0	0	0	6	15
680-689	9	5	1	5	3	1	1	1	0	0	6	17
690-699	8	4	1	0	1	0	0	0	0	0	10	4
700-709	9	2	0	0	0	0	0	0	0	2	11	25
710-719	15	3	3	0	0	0	0	0	0	0	8	8
720-729	18	5	2	0	0	0	0	0	1	1	20	29
730-739	9	1	5	0	1	0	0	0	0	0	13	34
740-749	34	4	5	0	0	0	0	0	0	0	18	5
750-759	32	3	2	0	1	0	0	0	0	1	15	0
760-769	19	4	3	3	0	0	0	0	0	2	25	0
770-779	21	5	8	7	1	0	0	0	0	2	16	0
780-789	22	7	3	10	0	1	0	1	0	3	17	0
790-799	15	10	2	7	8	1	0	3	0	4	19	0
800-809	11	6	3	1	1	0	0	1	1	7	15	0
810-819	7	11	4	0	4	0	0	0	0	4	12	0
820-829	4	10	3	1	1	0	0	0	0	13	5	0
830-839	4	9	8	0	0	0	0	0	0	9	10	0
840-849	0	22	1	2	0	0	0	0	0	7	5	0
850-859	0	20	10	3	2	0	0	0	1	17	0	0
860-869	0	14	6	5	0	0	0	1	0	22	0	0
870-879	0	17	6	6	4	0	1	3	0	16	0	0
880-889	0	15	3	3	6	0	1	0	0	18	0	0
890-899	0	20	7	2	2	0	0	0	0	20	0	0
900-909	0	12	10	3	0	0	1	0	0	21	0	0
910-919	0	20	16	11	1	0	0	0	1	20	0	0
920-929	0	10	12	3	0	0	0	1	1	17	0	0
930-939	0	8	7	10	5	0	1	2	0	23	0	0
940-949	0	3	18	9	11	1	2	3	4	27	0	0
950-959	0	0	19	8	3	1	5	1	18	16	0	0
960-969	0	0	20	9	2	0	1	5	37	0	0	0
970-979	0	0	24	9	7	0	1	5	38	0	0	0
980-989	0	0	19	6	15	2	12	4	36	0	0	0
990-999	0	0	16	13	3	1	1	12	39	0	0	0
1000-1009	0	0	14	14	4	0	4	5	43	0	0	0
1010-1019	0	0	10	18	14	9	18	2	46	0	0	0
1020-1029	0	0	0	28	2	0	3	72	4	0	0	0
1030-1039	0	0	0	37	18	5	8	79	0	0	0	0
1040-1049	0	0	0	35	92	0	195	76	0	0	0	0
1050-1059	0	0	0	0	73	276	51	0	0	0	0	0

Table 15. Frequency Distribution of Daily Solar Energy (Wh m^{-2}) from ETAC Data for Riyadh

Range	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
1500-1599	0	0	0	0	0	0	0	0	0	0	0	1
1600-1699	0	1	0	0	0	0	0	0	0	0	0	1
1700-1799	1	0	0	0	0	0	0	0	0	0	0	1
1800-1899	1	0	0	0	0	0	0	0	0	0	0	1
1900-1999	0	0	0	0	0	0	0	0	0	0	0	3
2000-2099	1	0	1	0	0	0	0	0	0	0	0	1
2100-2199	0	0	0	0	0	0	0	0	0	0	0	2
2200-2299	2	0	0	0	0	0	0	0	0	0	0	0
2300-2399	0	0	0	0	0	0	0	0	0	0	1	2
2400-2499	0	2	0	1	0	0	0	0	0	0	0	2
2500-2599	2	0	0	0	0	0	0	0	0	0	0	5
2600-2699	2	0	0	0	0	0	0	0	0	0	1	2
2700-2799	1	1	0	0	0	0	0	0	0	0	0	2
2800-2899	0	0	0	0	0	0	0	0	0	0	0	3
2900-2999	4	0	1	0	0	0	0	0	0	0	2	3
3000-3099	5	0	0	0	0	0	0	0	0	0	3	6
3100-3199	1	0	1	0	0	0	0	0	0	0	1	4
3200-3299	3	0	1	0	0	0	0	0	0	0	5	4
3300-3399	0	2	1	0	0	0	0	0	0	0	2	4
3400-3499	3	0	0	1	1	0	0	0	0	1	3	7
3500-3599	4	2	1	1	0	0	0	0	0	0	5	5
3600-3699	5	0	2	1	1	0	0	0	0	1	2	14
3700-3799	3	1	3	3	1	0	0	0	0	2	2	7
3800-3899	12	1	1	0	0	0	0	0	0	0	4	9
3900-3999	10	5	1	2	0	0	0	0	0	0	4	11
4000-4099	6	2	3	1	1	0	0	0	0	0	5	10
4100-4199	12	4	3	0	0	0	0	0	0	0	4	9
4200-4299	12	5	2	1	2	0	0	0	0	1	5	12
4300-4399	12	2	2	0	1	0	0	0	0	2	3	12
4400-4499	16	5	0	0	0	0	0	0	0	0	14	9
4500-4599	4	3	3	5	1	0	0	0	0	0	9	19
4600-4699	13	8	3	1	1	0	0	0	0	1	19	20
4700-4799	17	4	4	2	2	0	0	0	0	1	8	42
4800-4899	21	3	3	2	1	0	0	0	0	1	12	44
4900-4999	29	9	8	3	2	0	0	0	0	2	14	2
5000-5099	27	5	1	2	3	0	0	0	0	4	23	0
5100-5199	21	8	10	2	1	0	0	1	0	2	27	0
5200-5299	19	3	1	5	4	0	0	0	0	4	19	0
5300-5399	10	8	8	3	1	0	0	1	0	3	17	0

Table 15. Frequency Distribution of Daily Solar Energy (Wh m^{-2}) from ETAC Data for Riyadh (Continued)

Range	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
5400-5499	15	7	8	0	3	0	0	0	0	3	13	0
5500-5599	10	10	3	2	3	0	0	1	0	2	13	0
5600-5699	6	15	4	3	2	0	0	1	0	3	6	0
5700-5799	0	21	4	3	0	0	0	0	0	3	9	0
5800-5899	0	20	11	7	3	1	0	1	1	9	6	0
5900-5999	0	9	5	1	2	1	0	0	0	5	9	0
6000-6099	0	18	6	8	1	0	0	0	1	18	0	0
6100-6199	0	12	7	6	0	0	0	0	0	19	0	0
6200-6299	0	22	4	5	2	0	0	0	0	18	0	0
6300-6399	0	14	7	4	1	0	0	1	0	18	0	0
6400-6499	0	13	9	11	2	0	1	1	1	22	0	0
6500-6599	0	12	8	6	4	0	1	1	0	18	0	0
6600-6699	0	14	13	6	1	0	0	2	0	18	0	0
6700-6799	0	7	12	7	0	0	1	0	3	17	0	0
6800-6899	0	4	19	4	9	1	1	1	1	22	0	0
6900-6999	0	0	23	5	3	0	2	2	3	19	0	0
7000-7099	0	0	18	6	0	0	1	3	4	20	0	0
7100-7199	0	0	29	7	11	0	1	1	10	20	0	0
7200-7299	0	0	21	10	5	0	0	0	31	0	0	0
7300-7399	0	0	13	15	2	0	1	4	30	0	0	0
7400-7499	0	0	6	8	10	0	3	4	37	0	0	0
7500-7599	0	0	5	9	11	0	2	4	39	0	0	0
7600-7699	0	0	1	10	8	0	3	4	21	0	0	0
7700-7799	0	0	10	13	4	1	6	8	28	0	0	0
7800-7899	0	0	0	17	5	0	6	9	22	0	0	0
7900-7999	0	0	0	17	9	1	4	11	27	0	0	0
8000-8099	0	0	0	17	12	2	9	33	11	0	0	0
8100-8199	0	0	0	13	9	5	4	51	0	0	0	0
8200-8299	0	0	0	23	14	2	11	37	0	0	0	0
8300-8399	0	0	0	14	13	7	13	39	0	0	0	0
8400-8499	0	0	0	7	25	1	15	33	0	0	0	0
8500-8599	0	0	0	0	21	6	35	25	0	0	0	0
8600-8699	0	0	0	0	25	15	48	0	0	0	0	0
8700-8799	0	0	0	0	58	30	93	0	0	0	0	0
8800-8899	0	0	0	0	9	227	49	0	0	0	0	0
8900-8999	0	0	0	0	0	0	0	0	0	0	0	0

Table 16. Frequency Distribution of Daily Solar Energy (Wh m^{-2}) from ETAC Data for Qaisumah

Range	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
1500-1599	0	0	0	0	0	0	0	0	0	0	0	0
1600-1699	2	1	0	0	0	0	0	0	0	0	0	1
1700-1799	3	1	0	0	0	0	0	0	0	0	0	1
1800-1899	1	0	0	0	0	0	0	0	0	0	0	0
1900-1999	2	0	0	0	0	0	0	0	0	0	0	0
2000-2099	0	0	0	0	0	0	0	0	0	0	0	2
2100-2199	2	1	0	0	0	0	0	0	0	0	1	3
2200-2299	3	1	0	0	0	0	0	0	0	0	0	3
2300-2399	3	0	0	0	0	0	0	0	0	0	3	3
2400-2499	4	0	0	0	0	0	0	0	0	0	1	5
2500-2599	3	0	0	0	0	0	0	0	0	0	2	6
2600-2699	4	1	0	0	0	0	0	0	0	0	2	12
2700-2799	6	1	0	0	0	0	0	0	0	0	1	9
2800-2899	11	0	2	0	0	0	0	0	0	0	6	8
2900-2999	6	1	2	0	0	0	0	0	0	1	2	13
3000-3099	5	1	0	0	0	0	0	0	0	0	7	7
3100-3199	11	1	2	0	0	0	0	0	0	0	8	3
3200-3299	3	4	1	0	0	0	0	0	0	3	3	9
3300-3399	12	4	2	0	0	0	0	0	0	0	10	5
3400-3499	9	4	2	0	1	0	0	0	0	1	7	7
3500-3599	12	3	1	1	0	0	0	0	0	1	6	14
3600-3699	9	4	2	0	0	0	0	0	0	0	11	15
3700-3799	10	3	1	0	0	0	0	0	0	2	6	17
3800-3899	6	4	2	1	0	0	0	0	0	1	10	15
3900-3999	5	8	1	1	0	0	0	0	0	1	7	10
4000-4099	16	3	5	0	0	0	0	0	0	6	7	14
4100-4199	10	4	3	1	0	0	0	0	0	2	14	27
4200-4299	12	8	5	0	0	0	0	0	0	1	9	53
4300-4399	19	1	7	2	0	0	0	0	0	7	11	16
4400-4499	25	8	4	2	1	0	0	0	0	6	14	1
4500-4599	22	5	3	2	4	0	0	0	0	1	25	0
4600-4699	19	5	11	1	3	0	0	0	0	2	19	0
4700-4799	19	4	4	4	1	0	0	0	0	1	12	0
4800-4899	12	6	4	2	2	0	0	0	0	6	13	0
4900-4999	7	7	2	2	3	0	0	0	0	4	14	0
5000-5099	7	5	6	3	1	1	0	0	0	8	7	0
5100-5199	9	14	8	1	2	0	0	0	0	9	15	0
5200-5299	0	15	5	8	0	0	0	0	0	9	6	0

Table 16. Frequency Distribution of Daily Solar Energy (Wh m^{-2}) from ETAC Data for Qaisumah (Continued)

Range	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
5300-5399	1	21	3	5	4	0	0	0	0	5	3	0
5400-5499	0	13	4	5	2	1	0	0	0	6	5	0
5500-5599	0	15	3	3	3	0	1	0	0	10	3	0
5600-5699	0	21	0	9	2	0	0	0	0	14	0	0
5700-5799	0	15	9	6	3	0	0	0	0	20	0	0
5800-5899	0	15	8	2	2	0	0	0	0	14	0	0
5900-5999	0	12	5	2	1	1	0	0	0	11	0	0
6000-6099	0	10	15	5	5	0	0	0	1	12	0	0
6100-6199	0	12	10	3	3	0	0	1	2	17	0	0
6200-6299	0	7	8	4	4	0	0	0	2	12	0	0
6300-6399	0	6	6	7	7	0	0	0	3	12	0	0
6400-6499	0	7	14	8	6	0	0	2	0	14	0	0
6500-6599	0	0	16	10	9	0	0	0	4	13	0	0
6600-6699	0	0	19	5	5	0	1	1	1	15	0	0
6700-6799	0	0	11	4	9	0	0	0	4	15	0	0
6800-6899	0	0	11	9	7	0	2	0	1	15	0	0
6900-6999	0	0	16	5	5	1	0	2	20	2	0	0
7000-7099	0	0	15	7	4	0	0	0	30	0	0	0
7100-7199	0	0	9	6	9	1	0	0	22	0	0	0
7200-7299	0	0	12	8	9	1	2	1	36	0	0	0
7300-7399	0	0	11	14	2	0	1	1	26	0	0	0
7400-7499	0	0	6	7	4	1	2	2	24	0	0	0
7500-7599	0	0	4	7	4	1	1	0	19	0	0	0
7600-7699	0	0	8	13	8	1	1	10	18	0	0	0
7700-7799	0	0	2	18	2	2	2	3	16	0	0	0
7800-7899	0	0	0	19	5	1	5	11	26	0	0	0
7900-7999	0	0	0	21	6	0	3	11	15	0	0	0
8000-8099	0	0	0	21	7	1	3	33	0	0	0	0
8100-8199	0	0	0	20	14	2	6	46	0	0	0	0
8200-8299	0	0	0	4	7	1	4	45	0	0	0	0
8300-8399	0	0	0	9	13	3	5	45	0	0	0	0
8400-8499	0	0	0	3	22	5	7	33	0	0	0	0
8500-8599	0	0	0	0	16	6	11	32	0	0	0	0
8600-8699	0	0	0	0	16	6	56	0	0	0	0	0
8700-8799	0	0	0	0	30	9	55	0	0	0	0	0
8800-8899	0	0	0	0	37	22	86	0	0	0	0	0
8900-8999	0	0	0	0	0	233	56	0	0	0	0	0

Table 17. Frequency Distribution of Daily Solar Energy (Wh m^{-2}) from ETAC Data for Dhahran

Range	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
1500-1599	0	0	0	0	0	0	0	0	0	0	0	0
1600-1699	0	0	0	0	0	0	0	0	0	0	0	0
1700-1799	1	0	0	0	0	0	0	0	0	0	0	3
1800-1899	1	0	0	0	0	0	0	0	0	0	0	1
1900-1999	0	0	0	0	0	0	0	0	0	0	0	2
2000-2099	0	0	0	0	0	0	0	0	0	0	0	0
2100-2199	2	0	0	0	0	0	0	0	0	0	0	1
2200-2299	0	1	0	0	0	0	0	0	0	0	2	1
2300-2399	1	0	0	0	0	0	0	0	0	0	0	2
2400-2499	0	0	0	0	0	0	0	0	0	0	0	0
2500-2599	3	0	0	0	0	0	0	0	0	0	0	0
2600-2699	1	0	0	0	0	0	0	0	0	0	0	1
2700-2799	0	0	1	0	0	0	0	0	0	0	1	2
2800-2899	1	0	0	0	0	0	0	0	0	0	0	3
2900-2999	1	0	1	0	0	0	0	0	0	0	0	0
3000-3099	2	0	2	0	0	0	0	0	0	0	2	3
3100-3199	1	1	0	1	0	0	0	0	0	0	0	6
3200-3299	4	1	1	0	0	0	0	0	0	0	3	9
3300-3399	2	0	0	0	0	0	0	0	0	0	0	6
3400-3499	2	0	1	0	0	0	0	0	0	0	1	10
3500-3599	4	2	3	1	1	0	0	0	0	0	1	11
3600-3699	5	3	0	0	0	0	0	0	0	0	2	11
3700-3799	2	0	1	1	0	0	0	0	0	1	2	4
3800-3899	9	4	2	0	0	0	0	0	0	0	4	12
3900-3999	8	5	0	1	1	0	0	0	0	0	8	19
4000-4099	3	2	0	0	0	0	0	0	0	0	4	28
4100-4199	16	3	0	0	0	0	0	0	0	1	5	14
4200-4299	17	5	0	0	1	0	0	0	0	0	10	22
4300-4399	18	1	3	2	0	0	0	0	0	0	11	32
4400-4499	14	4	2	0	0	0	0	0	0	0	11	23
4500-4599	25	4	3	0	0	0	0	0	0	1	13	31
4600-4699	42	9	7	0	0	0	0	1	0	3	17	21
4700-4799	34	5	4	0	1	0	0	0	0	0	17	1
4800-4899	15	4	4	2	1	0	0	0	0	1	25	0
4900-4999	22	8	5	5	2	0	0	0	0	4	26	0
5000-5099	25	11	3	3	2	0	0	0	0	2	25	0
5100-5199	11	9	7	1	2	0	0	0	0	3	13	0
5200-5299	9	11	5	2	0	0	0	0	0	3	15	0
5300-5399	6	10	8	1	2	0	0	0	0	3	16	0

Table 17. Frequency Distribution of Daily Solar Energy (Wh m^{-2}) from ETAC Data for Dhahran (Continued)

Range	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
5400-5499	3	12	2	0	1	0	0	0	0	4	11	0
5500-5599	0	25	8	2	2	0	0	0	0	6	11	0
5600-5699	0	16	4	3	1	0	0	1	0	9	5	0
5700-5799	0	18	6	5	2	0	0	0	0	22	7	0
5800-5899	0	16	9	2	2	0	1	0	0	19	2	0
5900-5999	0	15	14	7	4	0	1	0	0	18	0	0
6000-6099	0	16	7	6	6	0	0	0	0	18	0	0
6100-6199	0	13	5	5	2	0	3	0	0	13	0	0
6200-6299	0	15	5	6	4	1	0	0	0	13	0	0
6300-6399	0	11	11	6	3	0	0	3	0	10	0	0
6400-6499	0	10	11	2	4	1	0	1	0	21	0	0
6500-6599	0	6	14	7	3	0	2	1	1	16	0	0
6600-6699	0	6	11	9	6	0	0	0	1	14	0	0
6700-6799	0	0	22	12	2	0	0	1	0	18	0	0
6800-6899	0	0	22	10	4	0	1	0	4	19	0	0
6900-6999	0	0	12	8	5	0	0	2	2	24	0	0
7000-7099	0	0	15	10	3	2	0	1	17	13	0	0
7100-7199	0	0	12	12	3	0	0	2	25	0	0	0
7200-7299	0	0	11	15	8	0	3	2	34	0	0	0
7300-7399	0	0	16	13	3	1	0	6	24	0	0	0
7400-7499	0	0	10	13	6	1	3	1	32	0	0	0
7500-7599	0	0	7	10	5	0	1	3	31	0	0	0
7600-7699	0	0	6	13	12	0	2	8	32	0	0	0
7700-7799	0	0	6	21	3	0	5	5	28	0	0	0
7800-7899	0	0	1	12	10	1	4	9	26	0	0	0
7900-7999	0	0	0	24	6	1	5	24	13	0	0	0
8000-8099	0	0	0	24	8	1	4	45	0	0	0	0
8100-8199	0	0	0	16	15	0	6	41	0	0	0	0
8200-8299	0	0	0	5	16	2	14	45	0	0	0	0
8300-8399	0	0	0	2	11	6	11	31	0	0	0	0
8400-8499	0	0	0	0	11	2	16	25	0	0	0	0
8500-8599	0	0	0	0	20	4	35	21	0	0	0	0
8600-8699	0	0	0	0	29	6	51	0	0	0	0	0
8700-8799	0	0	0	0	38	23	84	0	0	0	0	0
8800-8899	0	0	0	0	33	199	58	0	0	0	0	0
8900-8999	0	0	0	0	6	49	0	0	0	0	0	0

Table 18. Daily Solar Energy (kWh m^{-2}) from Various Sources for Saudi Arabia

[Source of Information]

	Month											
Annual	J	F	M	A	M	J	J	A	S	O	N	D
[De Jong (1973), values for 26.4°N, 47.7°E, interpolated from maps]												
6.0	3.9	4.8	5.6	7.1	7.7	7.9	7.9	7.4	6.5	5.5	4.3	3.4
[Landsberg et al. (1965), value for 26.4°N, 47.7°E, interpolated from map]												
6.7												
[Computed from ETAC data for January 1981-July 1990 for Riyadh, 24.700°N, 46.733°E]												
6.6	4.6	5.6	6.3	7.0	7.8	8.8	8.5	8.1	7.5	6.4	4.9	4.1
[Computed from ETAC data for January 1981-July 1990 for Dhahran, 26.267°N, 50.167°E]												
6.6	4.5	5.5	6.3	7.1	7.9	8.8	8.5	8.1	7.5	6.2	4.8	4.0
[Computed from ETAC data for January 1981-July 1990 for Qaisumah, 28.333°N, 46.117°E]												
6.4	3.9	5.1	6.0	7.0	7.6	8.8	8.7	8.2	7.3	5.8	4.2	3.6
[Bishop and Rossow (1991), values for 26.4°N, 47.7°E, interpolated from maps]												
(1983)							8.2					
(1984)	4.8						8.2					
(1985)	4.2											
[Mani et al. (1967), values for 26.4°N, 47.7°E, interpolated from maps]												
6.4	4.2			7.7			8.6			5.8		
[Said and Abdelrahman (1989) for 1985 for Dhahran, 26.383°N, 50.000°E, tabular values]												
5.8	3.7	5.1	5.3	5.7	6.8	8.0	7.3	7.2	6.4	6.3	4.2	3.1
[Saudi Arabian National Center for Science and Technology (1983) for 1971-1980 for Riyadh, 24.567°N, 46.717°E, tabular values]												
5.1	3.5	4.6	5.1	5.5	5.6	6.1	6.1	5.9	5.7	5.3	4.5	3.6
[Saudi Arabian National Center for Science and Technology (1983) for 1971-1980 for Qatif, 26.55°N, 50.00°E, tabular values]												
4.7	2.7	3.8	5.0	5.3	6.2	6.9	6.7	5.9	5.0	3.9	2.6	2.6
[Raschke et al. (1991), values for 26.25°N, 46.25°E, grid point values from tables]												
(1985)	3.0	4.3	5.2	6.1	6.9	7.9	7.8	7.2	6.1	4.8	3.4	2.7
(1986)	3.1	4.2	5.5	5.9	7.4	8.0	7.8	7.2	6.2	4.9	3.5	3.0

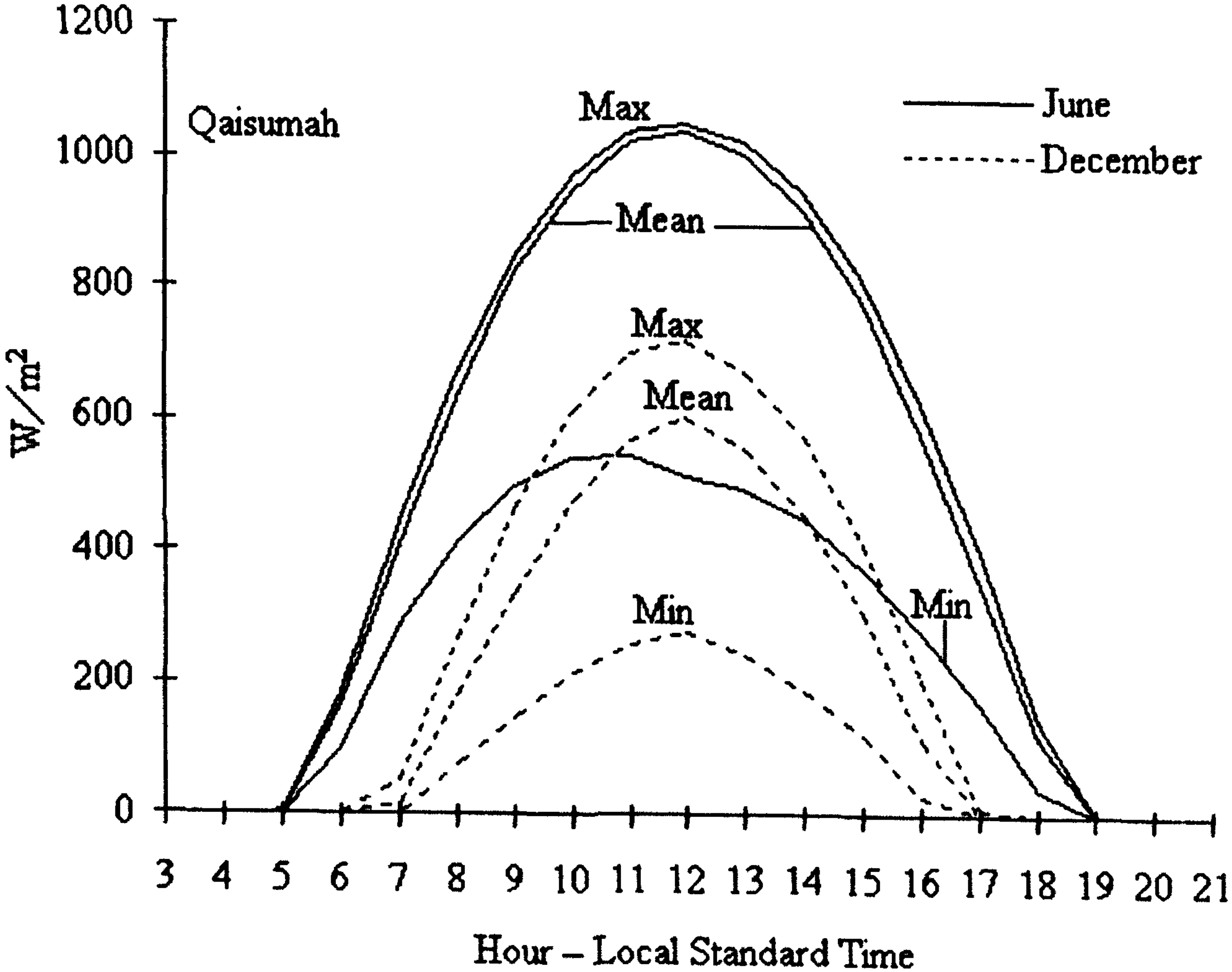

Figure 1. Diurnal Cycle of Maximum, Mean, and Minimum Solar Irradiance at Qaisumah for June 1981–90 and December 1981–89

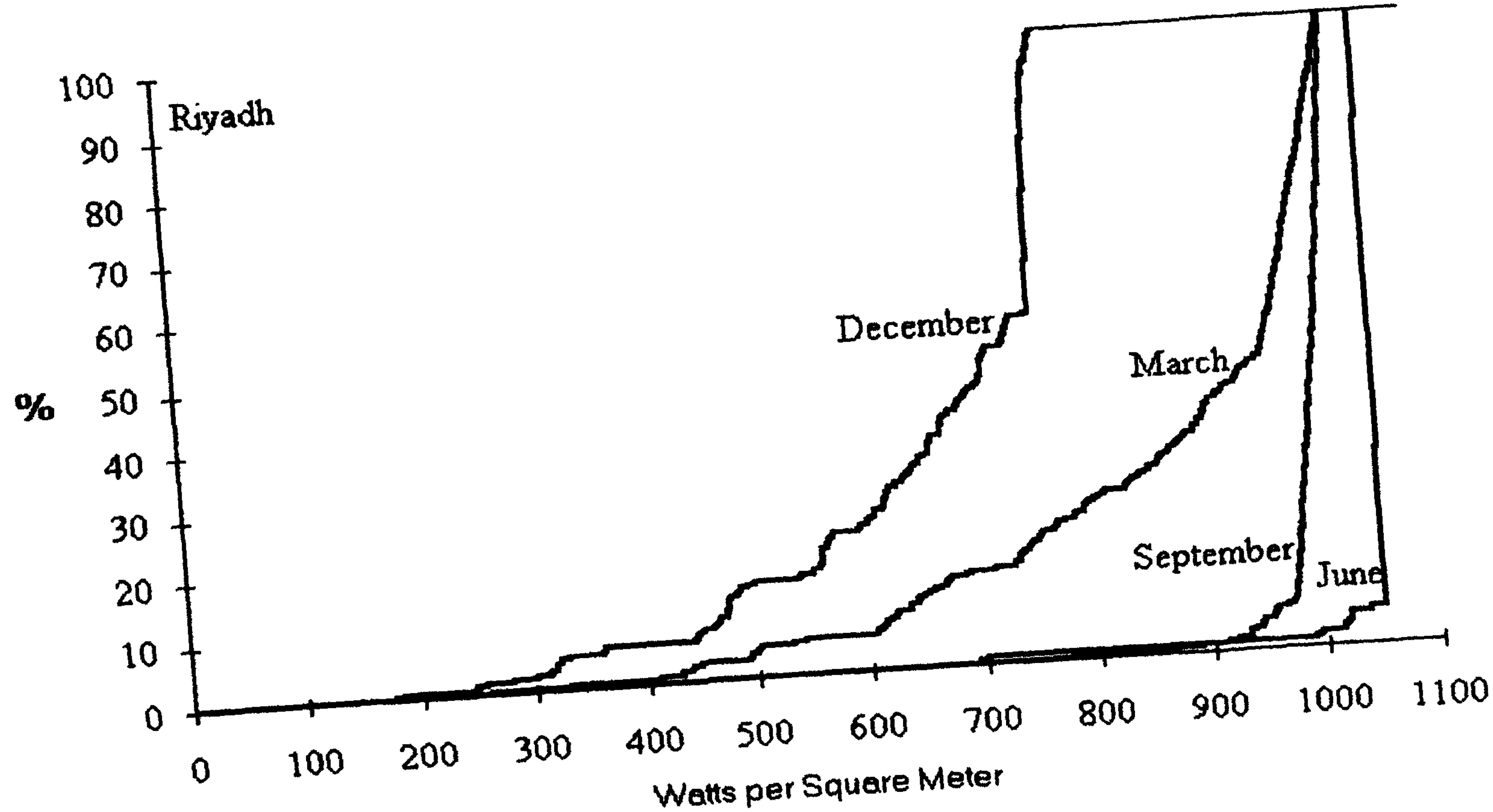

Figure 2. Cumulative Distribution of Solar Irradiance at 0900 UTC (Noon Local Time) Based on ETAC Data for Riyadh

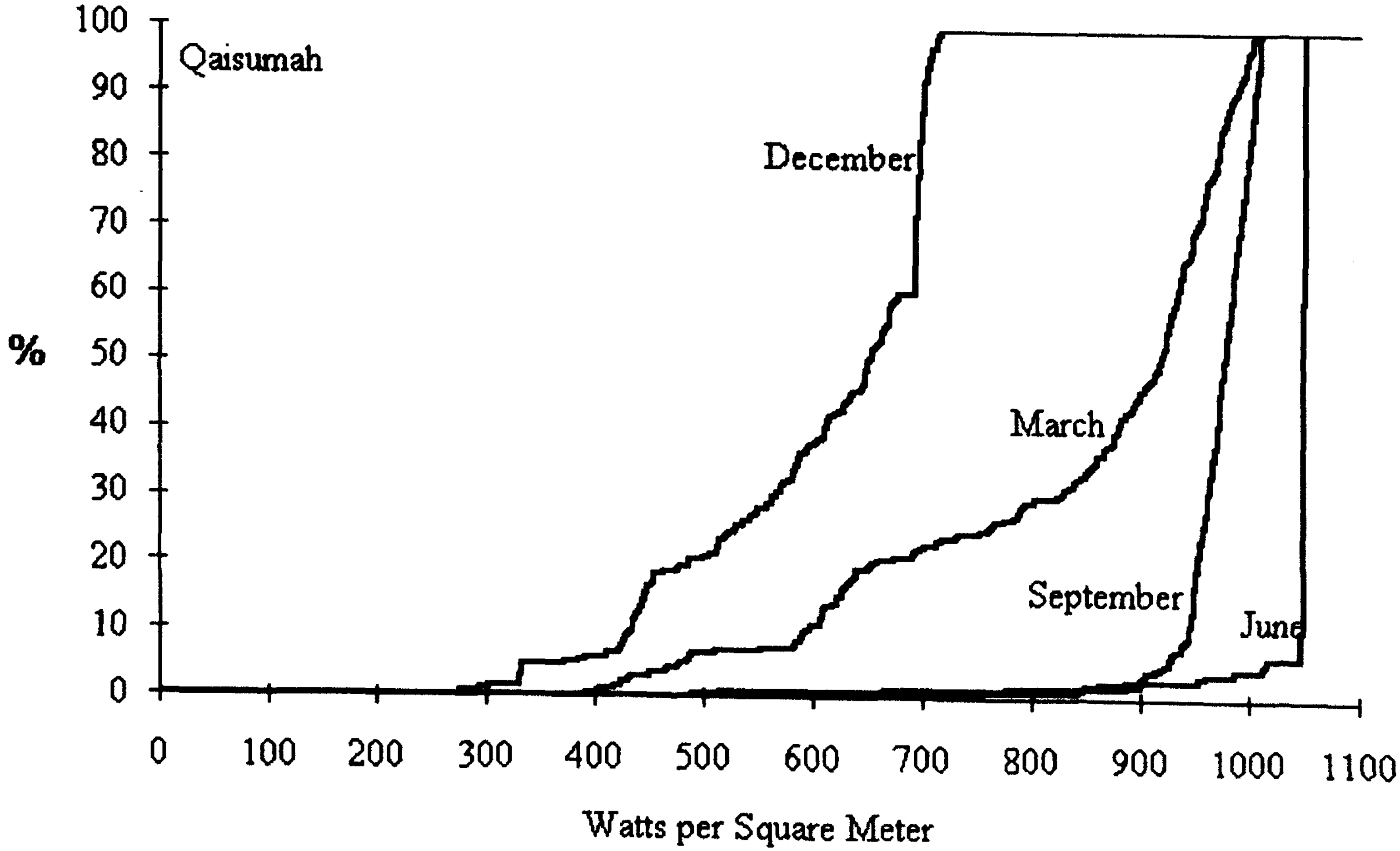

Figure 3. Cumulative Distribution of Solar Irradiance at 0900 UTC (Noon Local Time) Based on ETAC Data for Qaisumah

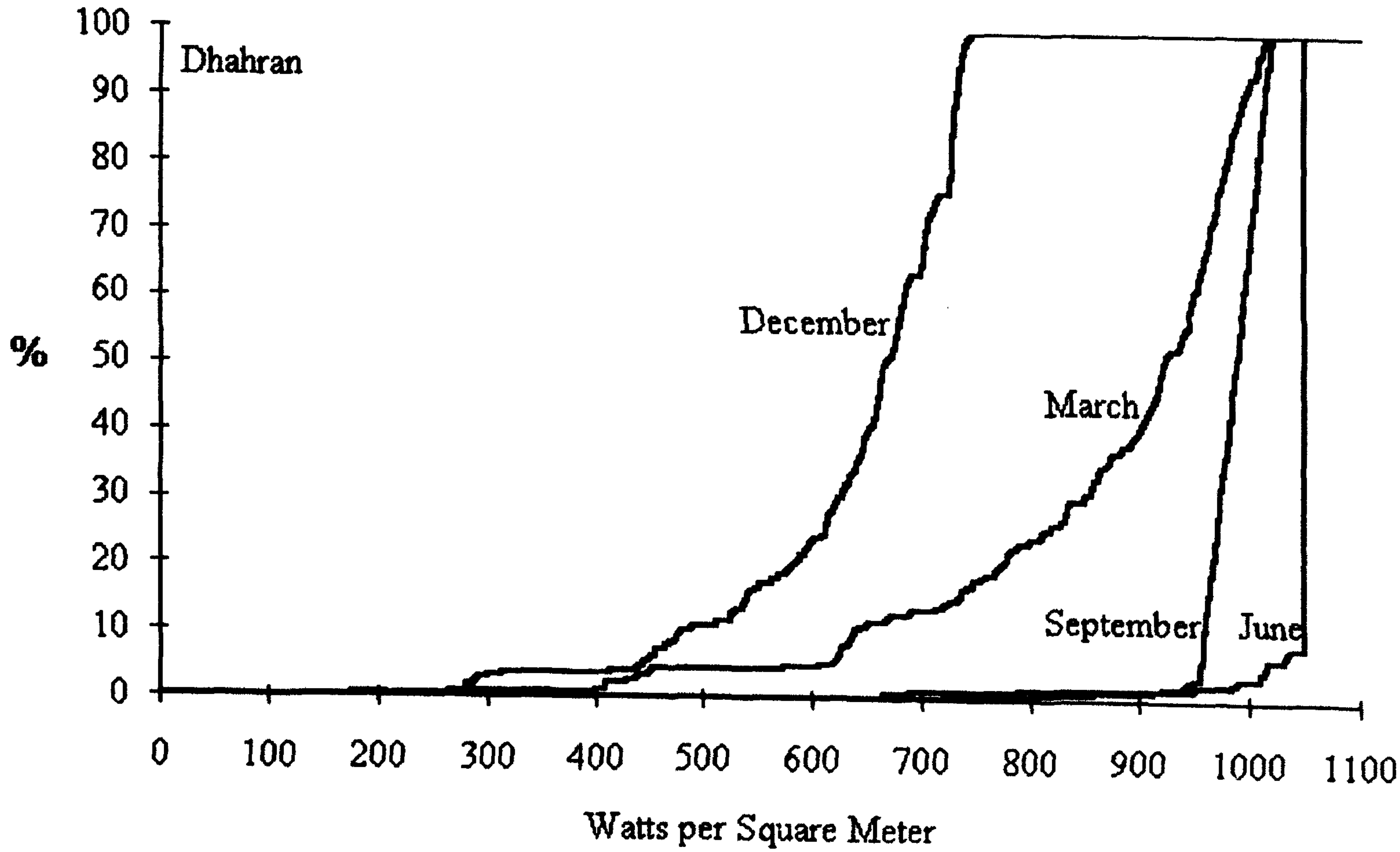

Figure 4. Cumulative Distribution of Solar Irradiance at 0900 UTC (Noon Local Time) Based on ETAC Data for Dhahran

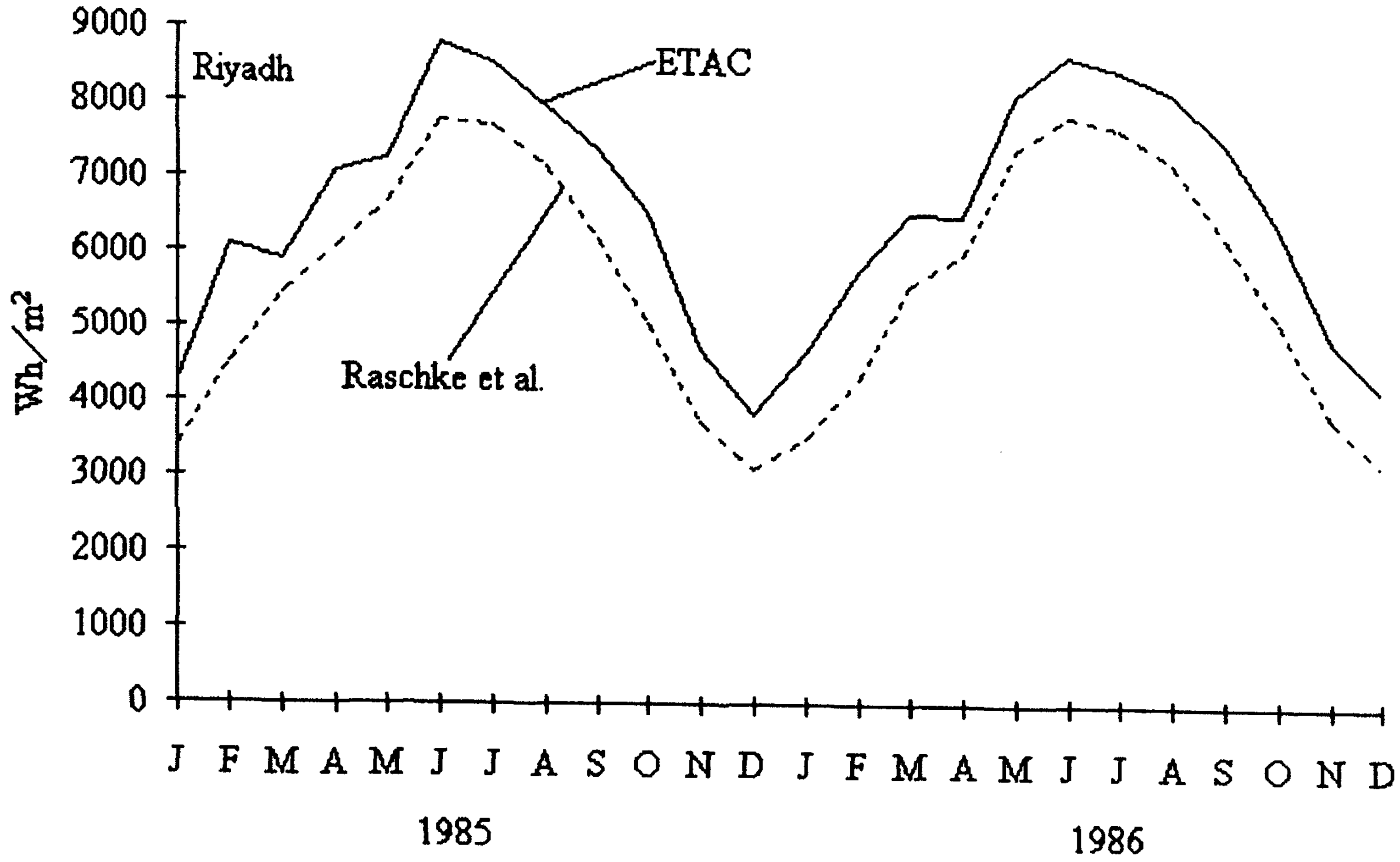

Figure 5. Comparison of Mean Daily Total Solar Energy During 1985 and 1986 from Different Sources for Riyadh

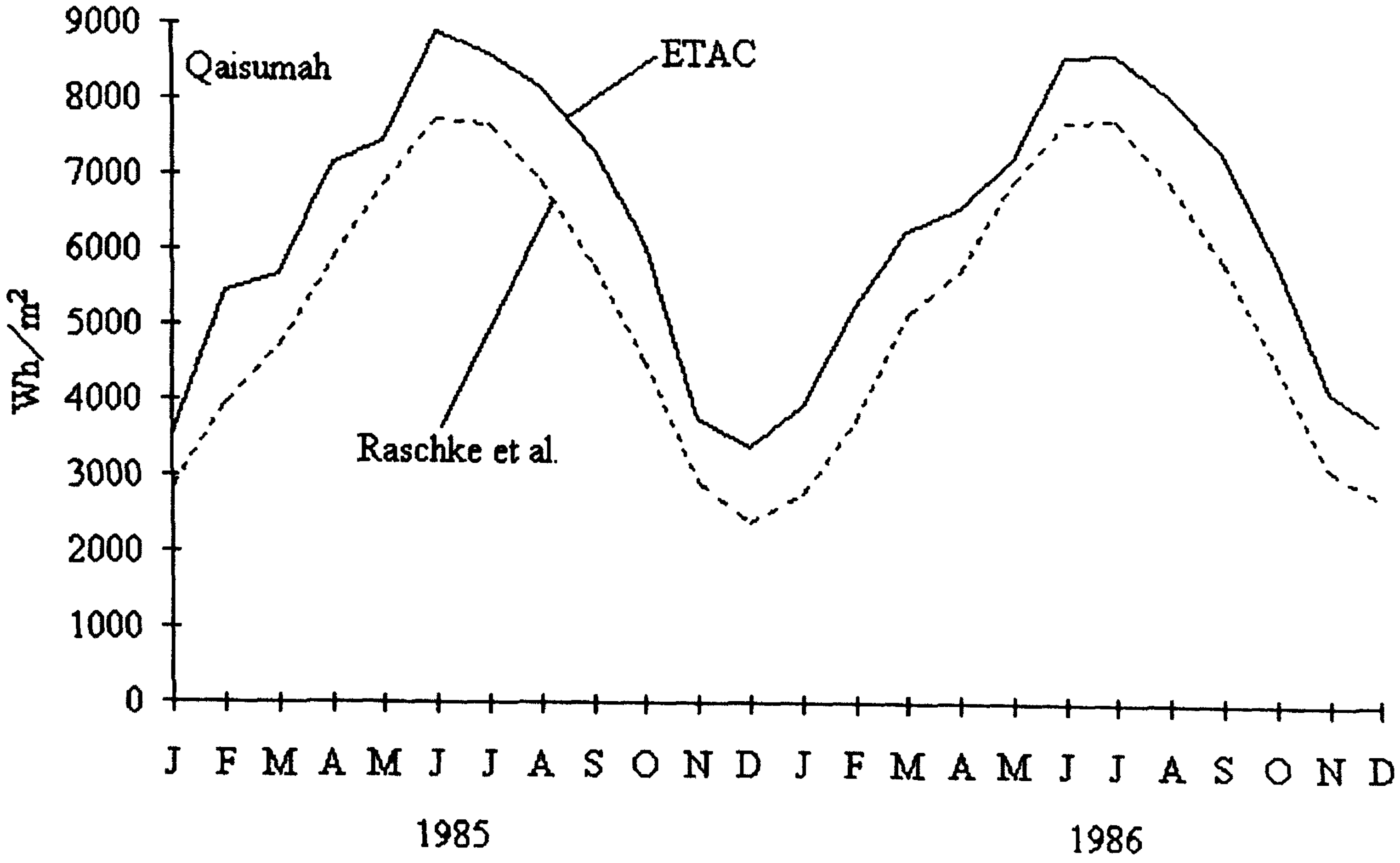

Figure 6. Comparison of Mean Daily Total Solar Energy During 1985 and 1986 from Different Sources for Qaisumah

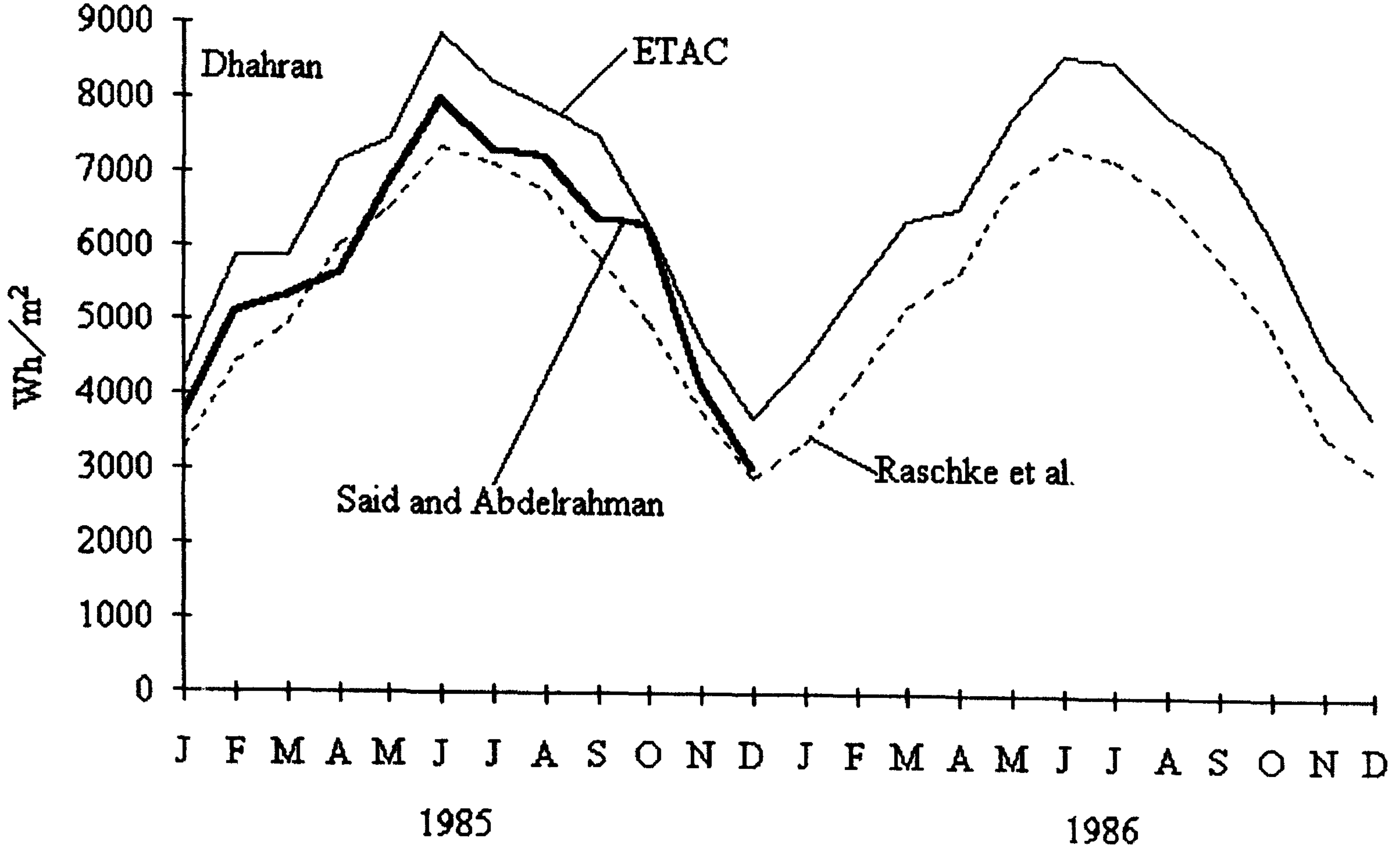

Figure 7. Comparison of Mean Daily Total Solar Energy During 1985 and 1986 from Different Sources for Dhahran

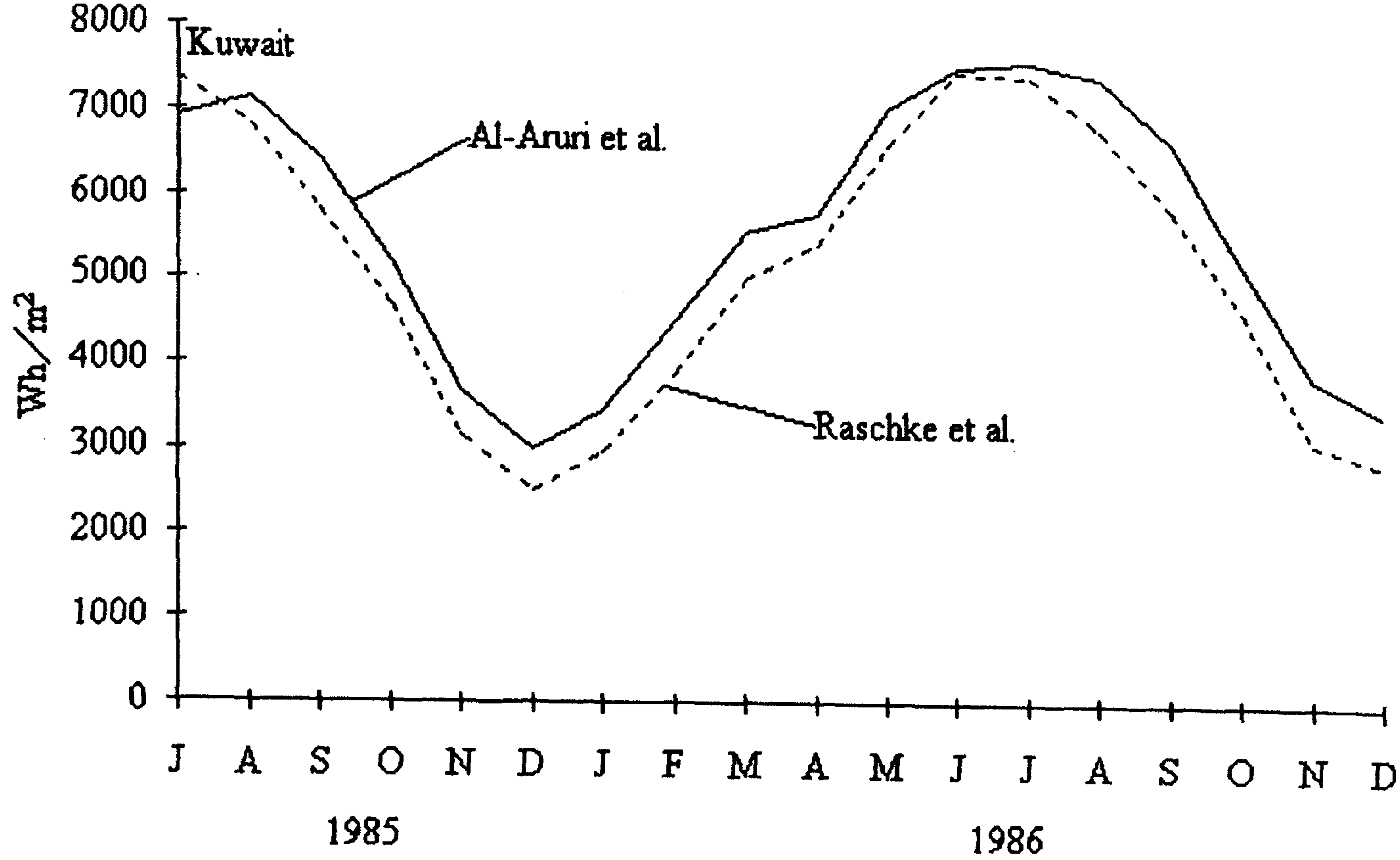

Figure 8. Comparison of Mean Daily Total Solar Energy During 1985 and 1986 from Different Sources for Kuwait

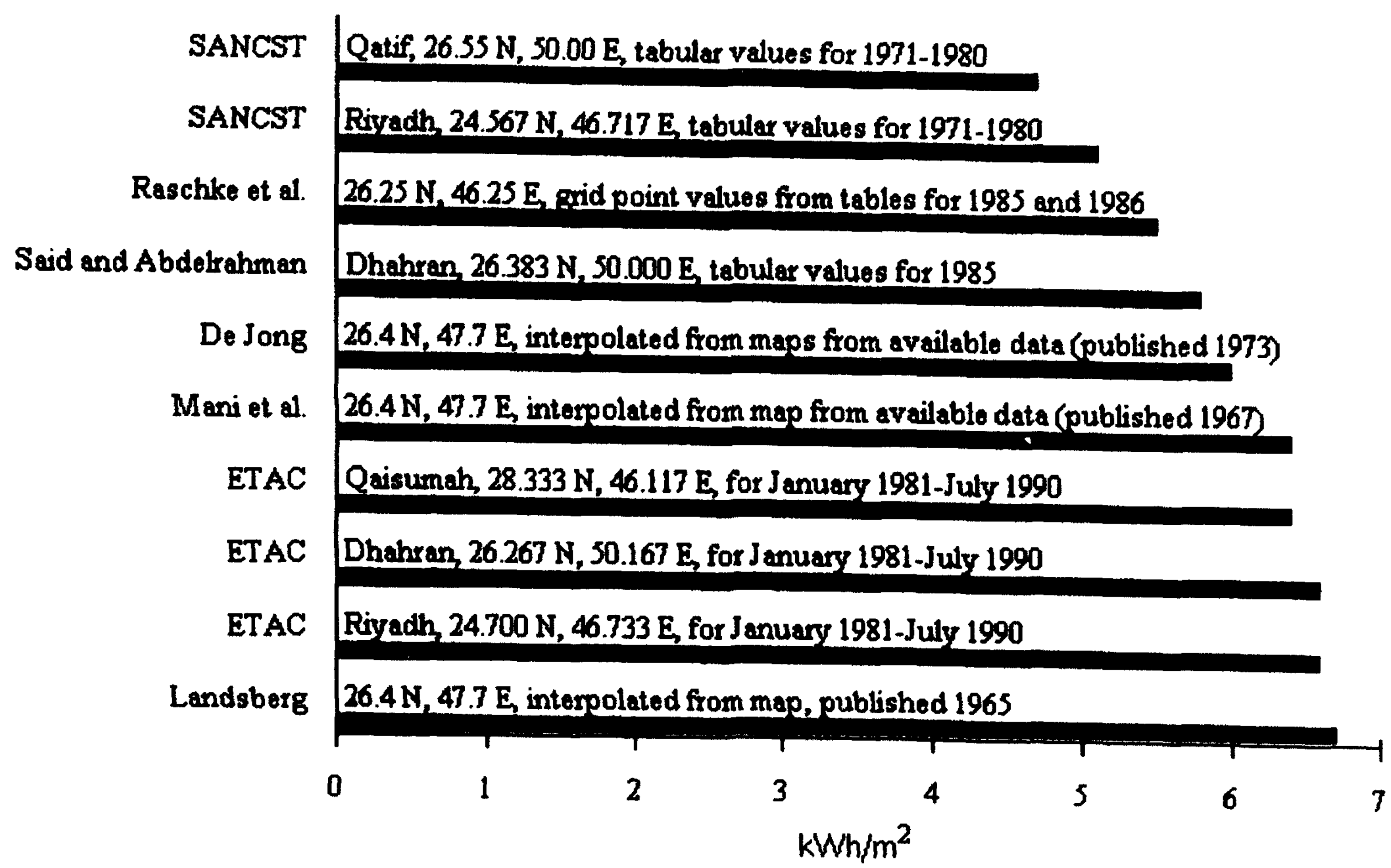

Figure 9. Mean Annual Daily Solar Energy (kWh m^{-2}) from Several Different Sources for Saudi Arabia

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